Conception d'une unité pilote pour le traitement des sédiments de l'assainissement pluvial

Conception of a pilot plant for the treatment of runoff water sediments

F. Pétavy*, V. Ruban*, J-Y. Viau**, P. Conil***

* Laboratoire Central des Ponts et Chaussées, Veronique.ruban@lcpc.fr
  B.P. 4129, 44341 Bouguenais cedex, France.

** Saint Dizier Environnement, jyviau@saintdizierenvironnement.fr
  rue Gay Lussac, BP 09-Zone industrielle, 59147 Gondecourt, France.

*** BRGM, SGR/PdL, p.conil@brgm.fr
  1 rue des Saumonières, BP 92342, Nantes cedex 03, France.

RESUME

Ce travail a pour objectif le développement d'une unité pilote de traitement des sédiments de l'assainissement pluvial ; les techniques retenues pour ce traitement sont l'attrition et la séparation granulométrique. Des essais préliminaires réalisés en laboratoire sur 6 sédiments différents montrent que 45 à 75 % d'un sédiment donné peuvent être valorisés. Ces résultats sont utilisés pour la conception de l'unité pilote qui permet de séparer 4 fractions. Les polluants (matière organique et métaux traces) sont concentrés dans la fraction fine (< 60 µm) qui sera incinérée ou mise en décharge. La fraction > 30 mm qui représente moins de 5 % de la masse initiale, suivra la filière des déchets ménagers. Enfin, les fractions > 2 mm et 60 µm-2 mm pourront quant à elles être valorisées si leurs caractéristiques géotechniques sont satisfaisantes.

ABSTRACT

The aim of this study is to develop a pilot unit based on attrition and sieving for the treatment of runoff water sediments. Preliminary laboratory tests carried out on 6 sediments with different characteristics show that 45 to 75 % of a given sediment can be re-used. These results are used for the conception of the pilot unit which allows to separate 4 fractions. The pollutants (organic mater and trace metals) are concentrated in the fine fraction (< 60 µm) which will be incinerated or landfilled. The coarse fraction (> 30 mm), generally less than 5 % will be considered as a domestic waste. Finally, the > 2 mm and 60 µm-2 mm fractions representing between 45 and 75 % of the bulk sediment are likely to be re-used (as road embankment) in case their geotechnical characteristics are good.

KEYWORDS

Pilot plant, pollution, retention/infiltration pond, sediments, treatment.
1 CONTEXT AND OBJECTIVES

The management of runoff has been an environmental priority for several decades. Indeed, stormwater runoff has been identified as one of the leading causes of degradation in the quality of receiving waters (Gromaire-Mertz et al., 2001; Lee et al., 2002). As a consequence, retention ponds have been built to control these effluents (Nightingale, 1987; Yousef et al., 1994). Their initial role was to control water flow during rainstorms, but they also proved useful by virtue of allowing road particles to settle and preventing them from entering the environment. However, the sediments are often polluted with heavy metals and hydrocarbons (Lee et al., 1997; Farm, 2001; Durand et al., 2004; Durand et al., 2005) and can present a risk for the environment and human health.

Although several studies have focused on these sediments (Backström, 2001; Durand, 2003) ponds managers are generally faced with a lack of knowledge as how the by-products from basins could be usefully recovered and reused. Yet, about 5 million tons (dry weight) from the dredging of ponds and road ditches are produced each year in France. Due to changes in laws and disposal in landfills becoming more restrictive, other solutions such as recycling have to be found.

This paper presents the approach developed for the conception of a pilot unit aimed at treating the sediments from stormwater runoff. This work is part of a global project on the characterization and treatment of such sediments.

2 MATERIALS AND METHODS

2.1 The sediments

A bulk characterization of the sediments including the determination of trace metals and hydrocarbons was made in order to select the sediments. Two criteria were retained: d50 > 70 µm and at least one metal concentration greater than the intervention value of the Dutch standard for polluted soils used as reference (Spierenburg and Demanze, 1995). Six pond sediments collected in the regions of Nantes, Paris, Lyon and Nancy (France) were studied. In each case, about 2.5 tons of sediments were taken by means of a backhoe loader, table 1 presents 4 of the selected sites.

<table>
<thead>
<tr>
<th>Nature</th>
<th>Location in France</th>
<th>Size (m²)</th>
<th>Trafic (veh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AhAh</td>
<td>Retention</td>
<td>Crosne (Paris)</td>
<td>593</td>
</tr>
<tr>
<td>Lyon</td>
<td>Infiltration</td>
<td>A 47 (Lyon – St Etienne)</td>
<td>620</td>
</tr>
<tr>
<td>Flavigny</td>
<td>Retention</td>
<td>Flavigny sur Moselle</td>
<td>3 000</td>
</tr>
<tr>
<td>Cheviré</td>
<td>Infiltration</td>
<td>S W of Nantes</td>
<td>780</td>
</tr>
</tbody>
</table>

Table 1 : Location and characteristics of the studied basins

2.2 Laboratory attrition tests

The attrition tests are performed in a cylab.1 Laboratory Attrition Scrubber. The attrition apparatus consists of three bladed impellers and a closely fitted stainless steel tank with a lid. The impellers are fabricated into one piece with all the blades facing at opposing pitches and are attached to the end of the shaft.

Attrition scrubbing performances and therefore the percentage of fine particles produced are generally studied by varying a number of parameters, including cut off threshold, residence time, solid density and impeller speed. Freeman et al. (1993)
presented a typical testing matrix to determine the optimal conditions. Pearl et al. (1994) found that extending the period of attrition scrubbing, in order to remove further contaminants coatings, had a limited effect. In this paper, only the results obtained in the optimal experimental conditions will be presented. The cut off thresholds are 80 µm and 2 mm. The speed drive is set to 2125 rpm and the sediment (70 % solid) is attrited for 180 seconds.

2.3 The pilot plant

The principle of the pilot plant is described in figure 1.

- Static screen: In order to remove the coarse debris, the materials pass over a static screen with a 30 mm aperture. The oversize fraction (> 30 mm) is collected and eliminated with the domestic waste. The fraction less than 30 mm is then forwarded to a vibratory screen through a conveyor.
- First separator: It includes two vibratory screens and a hydrocyclone. The material < 30 mm is passed over a vibratory screen with a 2 mm aperture while being intensely sprayed with high pressure water sprays. The 2 mm – 30 mm fraction is stockpiled without further treatment. The undersize fraction (< 2 mm) is injected under a pressure of 1.5 bar in a hydrocyclone. This equipment is used for sediment with less than 20 or 25 % solids to separate coarse and fine grain fractions. The size of separation is about 60 µm. The hydrocyclone overflow stream which contains the finer particles < 60 µm is steered towards the physico chemical treatment of water. The fraction > 60 µm is therefore partially dewatered with a second vibratory screen (60 µm aperture) before being introduced into the attrition scrubber.
- Attrition equipment: This machine has two cells each with a vertical tree and three levels of stirring paddles supplied by an electric engine of 3 kW.
- Second separator: it includes a hydrocyclone to separate the fine particles produced during the attrition and a vibratory screen to dewater the hydrocyclone underflow stream which contains the coarser particles (> 60 µm).
The treated sediments (> 60 µm) are collected at the exit of the vibratory screen. As for the first separator, the fine particles are treated with the overflow stream by a physico chemical treatment.

- Water treatment: The hydrocyclone overflow streams are injected into a lamella thickener. The fine particles sediment after the addition of a flocculant. The resulting clarified water is re-used within the circuit while the clarifier sludge is dewatered in a filter press.

### 2.4 Analysis protocols

For the chemical analyses, all the reagents used were analytical grade reagents (Merck Suprapur or Pro Analysis). All glassware was cleaned with 10% nitric acid and rinsed with ultra-pure water. Analyses were carried out on the different fractions of the sediment. Organic matter content (as determined by weight loss at 550°C) and trace elements were determined according to AFNOR standards (1999); the detailed protocols are described in Durand (2003). The Quality Assurance procedures currently used in the Division for Water and Environment from LCPC were applied, covering preparation of samples for testing, performing of tests, conservation of substances for testing and archiving. Quality is also monitored by blank tests (for all methods used in the laboratory), an internal quality check (reference solutions and materials) and an external quality check (inter-laboratory tests on water and sediments).

### 3 RESULTS AND DISCUSSION

#### 3.1 Laboratory attrition tests

The objective is to select a treatment procedure by which as much clean material as possible is recovered, while the pollutants are concentrated in a small volume ready for final destruction (incineration) or isolation from the environment.

#### 3.1.1 Characterisation of the Cheviré sediments

Organic matter percentages and trace metal concentrations in the Cheviré sediments are presented in table 2 and compared to the target and intervention values of the Dutch Standards for polluted soils. Although these threshold values have no legal significance in France, they are frequently used as reference values to interpret the presence of certain substances in soils.

<table>
<thead>
<tr>
<th></th>
<th>OM %</th>
<th>Cd (mg kg⁻¹)</th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheviré Sediment</td>
<td>11.9</td>
<td>1.1</td>
<td>74</td>
<td>281</td>
<td>31</td>
<td>305</td>
<td>1526</td>
</tr>
<tr>
<td>Dutch target value</td>
<td>-</td>
<td>0.8</td>
<td>100</td>
<td>36</td>
<td>35</td>
<td>85</td>
<td>140</td>
</tr>
<tr>
<td>Dutch intervention value</td>
<td>-</td>
<td>12</td>
<td>380</td>
<td>190</td>
<td>210</td>
<td>530</td>
<td>720</td>
</tr>
</tbody>
</table>

Table 2: Characterisation of the Cheviré sediment and comparison with the target and intervention values of the Dutch standard for polluted soils. OM: organic matter

The Cheviré pond is contaminated by organic matter (12%) and trace elements, specially zinc with 1526 mg kg⁻¹, i.e. 2.1 times the Dutch Standard intervention value. Concentrations of copper (281 mg kg⁻¹) and lead (305 mg kg⁻¹) are slightly higher than the intervention values for copper, slightly lower for lead. Concentrations of cadmium (1.1 mg kg⁻¹), chromium (74 mg kg⁻¹) and nickel (31 mg kg⁻¹) are close to or less than target values.
3.1.2 Treatment of the Cheviré sediments

Table 3 presents the trace element concentrations and mass percent of organic matter in the three particle size fractions after sieving at 80 and 2000 µm.

<table>
<thead>
<tr>
<th>Size (µm)</th>
<th>DM %</th>
<th>OM %</th>
<th>Cd mg kg⁻¹</th>
<th>Cr mg kg⁻¹</th>
<th>Cu mg kg⁻¹</th>
<th>Ni mg kg⁻¹</th>
<th>Pb mg kg⁻¹</th>
<th>Zn mg kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2000</td>
<td>13</td>
<td>7.1</td>
<td>0.5</td>
<td>45</td>
<td>154</td>
<td>20</td>
<td>165</td>
<td>853</td>
</tr>
<tr>
<td>80 - 2000</td>
<td>60</td>
<td>9.2</td>
<td>0.8</td>
<td>52</td>
<td>197</td>
<td>22</td>
<td>230</td>
<td>1036</td>
</tr>
<tr>
<td>&lt; 80</td>
<td>27</td>
<td>16.8</td>
<td>1.2</td>
<td>107</td>
<td>382</td>
<td>43</td>
<td>379</td>
<td>2119</td>
</tr>
</tbody>
</table>

Table 3: Characterisation of the different particle size fractions before attrition tests on the Cheviré sediment. DM: dry matter, OM: organic matter.

Trace element concentrations and organic matter percentages are very much higher in the fine fraction (< 80 µm) than those of the other two fractions. Copper (382 mg kg⁻¹ against 154 and 197 mg kg⁻¹) and Zn (2119 mg kg⁻¹ against 853 and 1036 mg kg⁻¹) concentrations are above the Dutch Standard intervention values. The other metal concentrations are also much higher and above the target values with 379 mg kg⁻¹ for lead, 107 mg kg⁻¹ for chromium and 43 mg kg⁻¹ for nickel.

Even though the 80 µm – 2 mm fraction is less contaminated, it nevertheless shows high concentrations. Attrition tests (180 seconds) were performed to attempt to remove pollutants from the intermediate fraction between 80 µm and 2 mm (70 % solid). The results are given in table 4.

<table>
<thead>
<tr>
<th>Size (µm)</th>
<th>DM %</th>
<th>OM %</th>
<th>Cd mg kg⁻¹</th>
<th>Cr mg kg⁻¹</th>
<th>Cu mg kg⁻¹</th>
<th>Ni mg kg⁻¹</th>
<th>Pb mg kg⁻¹</th>
<th>Zn mg kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 – 2000</td>
<td>69</td>
<td>4.0</td>
<td>0.4</td>
<td>26</td>
<td>83</td>
<td>12</td>
<td>135</td>
<td>396</td>
</tr>
<tr>
<td>&lt; 80</td>
<td>31</td>
<td>18.5</td>
<td>1.3</td>
<td>121</td>
<td>391</td>
<td>49</td>
<td>442</td>
<td>2369</td>
</tr>
</tbody>
</table>

Table 4: Mass percentage of dry matter (DM) and organic matter (OM), and concentrations of trace elements in the two particle size fractions after attrition tests on the Cheviré sediment.

First, a production of fine particles from the attrition process is noted, with 31 % of the less than 80 µm fraction created. The pollutant concentrations in this fraction are very high with 18.5 % of organic matter and metal concentrations very much higher than Dutch Standard intervention values, more specially for copper (391 mg kg⁻¹) and zinc (2369 mg kg⁻¹).

Consequently, contamination of the fraction 80 µm – 2 mm is greatly reduced with very low concentrations of trace elements: 83 mg kg⁻¹ for copper, against 197; 135 mg kg⁻¹ for lead, against 230; 396 mg kg⁻¹ for zinc, against 1036. Trace element concentrations in the attrited fraction are all below the Dutch Standard intervention values and the total organic matter content is 4 % (table 4). Sieving and attrition tests have brought about a very significant reduction in pollution and confirm the relationship between organic and inorganic pollution.

The evolution before and after treatment of the solid mass balance and trace element repartition in the different fractions are presented in figure 2.
After treatment, the percentage of fine particles (< 80 µm) increases from 27 % to 45 %.

The fraction < 80 µm contains 71 % of lead, 72 % of cadmium, 74 % of chromium and copper and 77 % of Zinc. The results are similar to those of Bricka et al. who obtained a better efficiency of physical treatment after attrition process.

With cut off thresholds of 80 µm and 2 mm, a speed drive of 2125 rpm, a slurry of 70 % solid and a residence time of 180 seconds, about 55 % of the Cheviré sediment can be re-used if the mechanic characteristics are good.

In these conditions, similar results are obtained with six others sediments showing that 45 to 75 % of the sediment can be recycled.

### 3.2 The pilot plant

#### 3.2.1 Characterization of the bulk sediments

Four pond sediments with different particle sizes selected among the sediments studied in the laboratory experiment were treated in the pilot unit. The sediment from Lyon was fine, with a d50 of 47 µm contrary to that of Flavigny with a d50 of 1110 µm. The Cheviré and AhAh sediments have a d50 of 109 µm and 248 µm, respectively.

The chemical characterization of the 4 sediments are presented in table 5.

<table>
<thead>
<tr>
<th></th>
<th>d50 (µm)</th>
<th>OM (%)</th>
<th>Cd (mg kg⁻¹)</th>
<th>Cr (mg kg⁻¹)</th>
<th>Cu (mg kg⁻¹)</th>
<th>Ni (mg kg⁻¹)</th>
<th>Pb (mg kg⁻¹)</th>
<th>Zn (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AhAh</td>
<td>248</td>
<td>13.5</td>
<td>2.6</td>
<td>226</td>
<td>197</td>
<td>107</td>
<td>357</td>
<td>1949</td>
</tr>
<tr>
<td>Lyon</td>
<td>47</td>
<td>10.8</td>
<td>0.7</td>
<td>68</td>
<td>104</td>
<td>35</td>
<td>148</td>
<td>405</td>
</tr>
<tr>
<td>Flavigny</td>
<td>1110</td>
<td>4.1</td>
<td>0.3</td>
<td>2979</td>
<td>99</td>
<td>18</td>
<td>16</td>
<td>127</td>
</tr>
<tr>
<td>Cheviré</td>
<td>109</td>
<td>16.0</td>
<td>1.0</td>
<td>81</td>
<td>314</td>
<td>29</td>
<td>138</td>
<td>1580</td>
</tr>
</tbody>
</table>

Table 5: Characteristics of the studied sediments. OM: organic matter

The Cheviré sediment contains 16.0 % of total organic matter compared to 13.5 % for AhAh, 10.8 % for Lyon and 4.1 % for the Nancy sediments. Except for Nancy, the percentages of organic matter are higher than those required for re-use.

As can be seen from table 5, most of sediments have high metal concentrations.
The AhAh and Cheviré ponds are highly contaminated with trace elements, more specially with copper (197 and 314 mg kg\(^{-1}\)) and zinc (1949 and 1580 mg kg\(^{-1}\)) the concentrations of which are higher than the intervention values of the Dutch Standard. The other metal concentrations are higher than the target values with the exception of chromium and nickel for the Cheviré pond.

The sediments from Lyon are less polluted with copper (104 mg kg\(^{-1}\)), nickel (35 mg kg\(^{-1}\)) and lead (148 mg kg\(^{-1}\)) concentrations being slightly higher than target values of the Dutch standard.

The Flavigny pond is very contaminated by chromium (2979 mg kg\(^{-1}\)) for which concentrations are 13 times higher than the Dutch Standard intervention values. The other metal concentrations are all below the target values except for Cu (99 mg kg\(^{-1}\)).

### 3.2.2 Characterisation of the treated sediments

The results of the solid mass balance in the different fractions resulting from the treatment of the Cheviré and Flavigny sediments are presented in table 6 together with OM percentages and trace element concentrations.

<table>
<thead>
<tr>
<th>DM</th>
<th>OM</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>mg kg(^{-1})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Flavigny | > 30 mm | 4 | 0 | - | - | - | - |
|          | 2 mm – 30 mm | 20 | 0.7 | 0 | 5884 | 131 | 18 | 16 | 127 |
|          | 60 µm – 2 mm | 50 | 2.5 | 0.1 | 475 | 43 | 15 | 103 | 286 |
|          | < 60 µm | 26 | 16.6 | 1.4 | 377 | 284 | 61 | 229 | 1035 |

| Cheviré | > 30 mm | 4 | - | - | - | - | - |
|         | 2 mm – 30 mm | 8 | 7.5 | 0.4 | 32 | 125 | 14 | 83 | 650 |
|         | 60 µm – 2 mm | 50 | 2.5 | 0.1 | 27 | 21 | 9 | 60 | 188 |
|         | < 60 µm | 38 | 25.2 | 1.6 | 114 | 496 | 43 | 268 | 2275 |

Table 6: Solid mass balances and characterisation of the different fractions resulting from the treatment in the pilot plant. DM: dry matter, OM: organic matter

Four main fractions are extracted from the unit:

- The screen oversize product (> 30 mm) represents 4 % and consists in plastic bottles, wood fragments, pebbles etc.. This fraction is collected and eliminated with the domestic waste without characterisation.
- The fraction 2 mm – 30 mm amounts to 8 % for Cheviré and 20 % for Flavigny by weight of the sediment. Chromium concentrations (5884 mg kg\(^{-1}\)) of the Flavigny sediment are very high and a recovery is impossible. With 7.5 % OM and metal concentration below the Dutch Standard intervention values, this Cheviré fraction can be re-used in case of non stringent uses.
- After treatment, the 60 µm – 2 mm fraction (50 % for both sediments) is largely decontaminated with only 2.5 % OM for both fractions and a sharp decrease in metal concentrations. For the Cheviré sediment, metal concentrations are all bellow the Dutch Standard target values except for Zinc (188 mg kg\(^{-1}\)) which is slightly higher. Chromium (475 mg kg\(^{-1}\)), Copper (43 mg kg\(^{-1}\)), lead (103 mg kg\(^{-1}\)) and Zinc (286 mg kg\(^{-1}\)) concentrations are slightly higher than the target values for the Flavigny sediment. In case the geotechnical characteristics are good a high rank re-use will be possible (road embankment).
• The < 60 µm fraction resulting from the treatment of the process water amounts to 38 % for Cheviré and 26 % for Flavigny. Furthermore, this fraction is heavily polluted with up to 25.2 % of organic matter and Zinc concentration reaching 2275 mg kg⁻¹ in the Cheviré sediment. This fraction will be landfilled.

4 CONCLUSION
This study shows that polluted sediments from runoff water can valuably be processed thanks to a pilot plant. Screening and attrition made it possible to concentrate pollutants in the fine particles and it is an undeniable advantage for subsequent treatment of the sediments.

Taking into account environmental, geotechnical and economic requirements between 50 % and 60 % of the Flavigny and Cheviré sediments, respectively can be re-used after a physical treatment by the pilot unit. This percentage can reach 75 % for other sediments (AhAh) considered in this study.

5 ACKNOWLEDGEMENTS
The authors would like to express their gratitude for the financial support provided from the Seine-Normandie Water Authority, the French Research Ministry and the SETRA (Service Technique des Routes et Autoroutes).

REFERENCES