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TREATMENT AND VALORISATION OF STORMWATER SEDIMENTS

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ABSTRACT

The objective of this research is to show how sediment micro-pollution, including heavy metals, hydrocarbons and PAHs, can be reduced by means of a physical treatment based on screening and attrition. The study was carried out on five stormwater sediments, the developed pilot unit allows to isolate pollutants in the fine particles, hence a possible reuse of the coarse, unpolluted fractions. Geotechnical tests carried out on the treated sediments show that most of these fractions are likely to be reused as road embankments, capping layers or pipe embankments. The remediation of stormwater sediments is indeed possible and the development of a mobile unit is actually under study. As sediment treatment is a wide problem, largely exceeding stormwater, ATTRISED process could be used for the remediation of other sediments such as river dredging sediments or sediments from sewer networks.

KEYWORDS*:* attrition, heavy metals, pilot plant, PAHs, pollution.

1. INTRODUCTION

The management of polluted sediments has become a world-wide problem; each year millions of tons of sediments are dredged and a real problem arises regarding their disposal (Färm, 2001). In France alone, some 5 million tons (dry weight) are dredged yearly from ponds and road ditches, 1 million tons are extracted from street sweeping and about 1.3 million tons are collected from treatment plants (Durand *et al.*, 2004; 2005). However, these sediments are often polluted with heavy metals, hydrocarbons (Lee *et al.*, 1997; Färm, 2001; Durand *et al.*, 2004; 2005) and polycyclic aromatic hydrocarbons (PAHs) (Durand, 2003) and can present a risk for the environment and human health. Due to changes in laws and disposal in landfills becoming more restrictive, other solutions such as recycling have to be found. Although several studies have focused on pond sediments (Backström, 2001; Clozel *et al.*, 2006), managers are generally faced with a lack of knowledge as how the by-products from basins could be usefully recovered and reused. The objective of this paper is to show how sediment micro-pollution, including organic matter, heavy metals, hydrocarbons and PAHs, can be reduced by means of a physical treatment; to achieve this objective, the so-called ATTRISED pilot plant was designed, which takes into account actual technical and economic criteria. Geotechnical tests were carried out in order to make sure that a valorisation of the treated sediments is possible.

2. MATERIALS AND METHODS

2.1 The sediments

The experimentations were carried out on polluted sediments from retention ponds and street sweeping collected in France. Five sediments were chosen for the pilot study, in each case about 2.5 tons of sediment were taken by means of a backhoe loader; table 1 presents the characteristics of the studied sites.

Table 1. Location and characteristics of the studied sites

	Nature	Location in France	Size (m^2)	Traffic (veh/day)
AhAh (Paris)	Retention	Crosne (Paris)	593	-
Lyon	Infiltration	A 47 (Lyon – St Etienne)	620	72 200
Cheviré (Nantes)	Infiltration	S W of Nantes	780	80 000
Bordeaux	Street sweeping	Bordeaux centre	-	-
Lille	Street sweeping	Lille centre	-	-

2.2 Chemical analyses

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). Hydrocarbons were determined according to AFNOR X31-410 (1994); the extracted solvent used is the chlorofluorocarbon and the Fourier Transform-Infrared (FT-IR) spectroscopy was carried out on a Perkin Elmer Paragon 100. Polycyclic aromatic hydrocarbons (PAH) were determined according to AFNOR XP X33-012 (2000); the sediments were treated with hexane and acetone (v/v) in a soxhlet to extract lipids. The solvent was evaporated and removed with hexane before to be treated on a column of sodium sulfate and aluminium sulfate. The final residue was then analysed by gas chromatography and PAH were detected by application of fluorometric detector. Quality Assurance, covering preparation of samples for testing, performing of tests, conservation of substances for testing and archiving was used. Quality is also monitored by blank tests, an internal quality check (reference solutions and materials) and an external quality check (inter-laboratory tests on water and sediments).

2.3 Pilot plant

Preliminary laboratory tests were carried out and showed that attrition can be valuably used to remove fine particles coated on coarser ones. It was therefore decided to design a pilot plant based on sieving and attrition. The principle of the ATTRISED pilot plant is described in Figure 1.

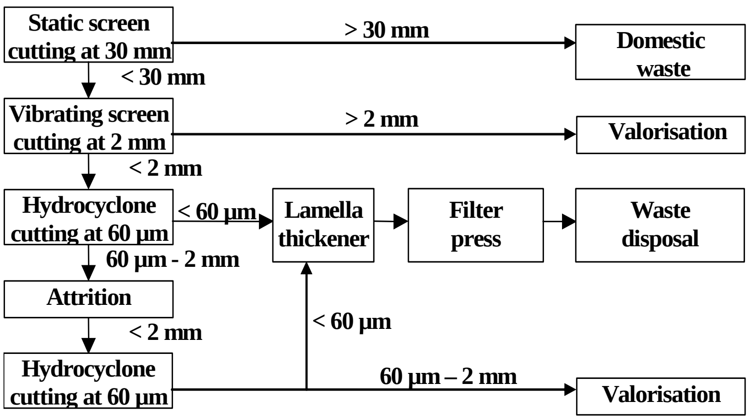

Figure 1. Scheme of the pilot plant

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 into 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 physicochemical treatment of water. The > 60 µm fraction 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 physicochemical 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 reused within the circuit while the clarifier sludge is dewatered in a filter press.

3. RESULTS AND DISCUSSION

3.1 Characterization of the bulk sediment

Table 2 presents the particle size distribution (d10, d50, d90, %<63 µm) and the chemical characteristics of the studied sediments. Trace elements, hydrocarbons and phenanthrene concentrations are compared to the target and intervention values of the Dutch Standards for polluted soils used as reference (Spierenburg and Demanze, 1995). 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 2. Characteristics of the studied sediments.
[a]OM: Organic Matter ; [b]THc : Hydrocarbons; [c]Phe: Phenanthrene

	d10	d50 µm	d90	<63 µm %	OM[a] %	THc[b] mg kg^{-1}	Phe[c] µg kg^{-1}	Cr	Cu mg kg $^{-1}$	Pb	Zn
Cheviré	8	109	1890	40	15.6	3540	388	69	306	138	1180
AhAh	3	25	210	71	12.0	4955	683	68	139	244	631
Lyon	5	47	1970	56	10.8	794	510	74	104	148	405
Bordeaux	74	901	3995	9	6.1	1297	232	58	65	122	281
Lille	7	231	3612	35	5.9	823	727	202	97	106	356
Dutch target value						50	45	100	36	85	140
Dutch intervention value						5000		380	190	530	720

Particle analysis indicate that in the 5 sediments, the particle size distributions are very different. The main consequences of these heterogeneous distributions will be the percentages of each treated fraction. Contrary to Lyon and AhAh sediments which are very fine with 71 and 56 % of particles less than 63 µm, all other sediments have a d50 higher than 100 µm and present interesting physical characteristics for this treatment. Among the studied sediments, all are contaminated by organic or inorganic pollutants. Three of them, Cheviré, AhAh and Lyon, have organic matter percentages higher than 10 %, value required for reuse by the technical guidelines on embankment and capping layer construction (SETRA-LCPC, 2003). Furthermore, the organic matter percentages must be lower than 3 % for a high rank reuse (SETRA-LCPC, 2003) and in the other sediments, OM concentrations is around 6 %. Bulk sediments also have very high hydrocarbon concentrations ranging from 794 mg kg^{-1} for Lyon to 4955 mg kg^{-1} for AhAh sediments. Furthermore, PAH, and especially phenanthrene concentrations, are also studied in the bulk sediments and their concentrations are largely higher than the Dutch Standard (45 µg kg^{-1}). Most of the sediments also have high metal concentrations. The Cheviré sediments are heavily contaminated with trace elements, especially with copper (306 mg kg^{-1}) and zinc (1180 mg kg^{-1}) whose concentrations are higher than the Dutch Standard intervention values. Lyon sediments are less polluted, yet copper, nickel, lead and zinc concentrations lie between the target and intervention values. The street sweeping sediments are also contaminated with trace elements, specially Lille sediments with all metal concentrations lying above the target values.

3.2 Pilot plant treatment

Although 7 sediments were treated, the results presented here will concern 2 sediments only, one from the Cheviré infiltration pond in Nantes and one from street sweeping in Lille.

Solid mass balances

Four main fractions are extracted from the pilot plant (Figure 1) according to their particle sizes: > 30 mm, 2 mm – 30 mm, 60 µm – 2 mm and < 60 µm. The solid mass balances of each fraction for Cheviré and Lille sediments are presented in Figures 2 and 3.

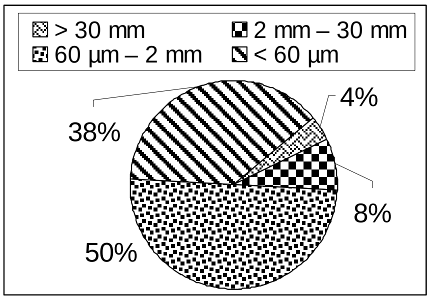

Figure 2. Solid mass balances of each fraction from Cheviré sediments

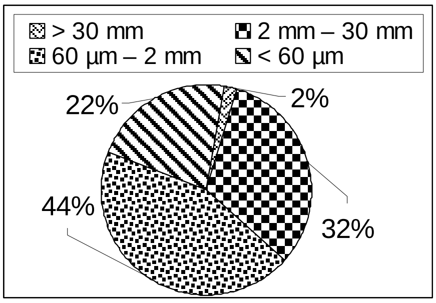

Figure 3. Solid mass balances of each fraction from Lille sediments

The screen oversize product (> 30 mm) consists in plastic bottles, wood fragments, pebbles etc. This fraction, which makes up a small part of the samples with 4 % for Cheviré and 2 % for Lille sediments, will be collected and eliminated with the domestic waste without physical and chemical characterizations. The < 60 µm fraction resulting from the treatment of the process water amounts to 38 % for Cheviré and 22 % for Lille. In their laboratory studies (Petavy and Ruban, 2007) show that this fraction is heavily polluted and will be landfilled. The 2 mm – 30 mm and the 60 µm – 2 mm fraction which amounts to 58 % for Cheviré and 76 % for Lille by weight of the sediment, may be reused, if their chemical, environmental and geotechnical characteristics are in agreement with the different use requirements.

Characterization of the treated fractions

Our objective is to study the micro pollution distribution between the different treated fractions in order to isolate polluted fractions and reuse clean fractions. Except for the > 30 mm fraction considered as a domestic waste, organic matter (MO), hydrocarbon (THc), phenanthrene (Phe) and trace element concentrations are determined in the different fractions resulting from the sediment treatment (Figures 4 and 5).

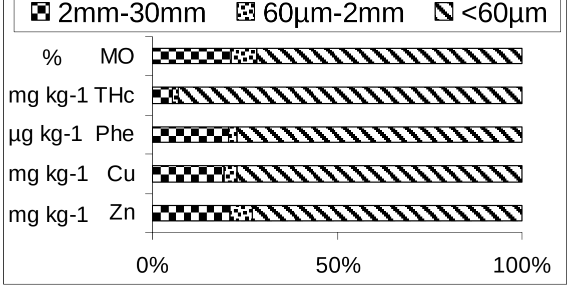

Figure 4. Micro-pollution distribution in the treated fractions from Cheviré sediments

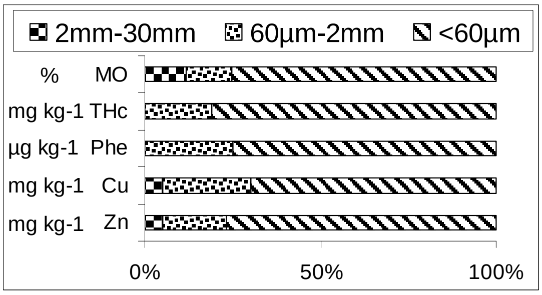

Figure 5. Micro-pollution distribution in the treated fractions from Lille sediments

As can be seen from figures 4 and 5, physical treatment allows a drastic decrease in micro-pollutant concentrations in the 2 mm – 30 mm and 60 µm – 2 mm fractions, while the pollutants concentrate in the finest fraction less than 60 µm. Indeed, the < 60 µm fraction is heavily polluted with organic matter percentages ranging from 16.5 % for Lille to 25.2 % for Cheviré, high concentrations of hydrocarbon and phenanthrene with 1318 mg kg^{-1} and 964 µg kg^{-1}, respectively for Lille sediments and 6431 mg kg^{-1} and 691 µg kg^{-1}, respectively for Cheviré sediments. Furthermore, trace element concentrations are also very high with for example, 2275 mg kg^{-1} of zinc for Cheviré and 222 mg kg^{-1} of copper for Lille sediments. If the fraction less than 60 µm must be landfilled, the two other fractions are largely decontaminated and may be reused in case the geotechnical characteristics are good. The 60 µm – 2 mm fractions for Cheviré and Lille sediments are largely decontaminated with 108 and 308 mg kg^{-1} of hydrocarbons, 20 and 323 µg kg^{-1} of phenanthrene, respectively. Furthermore, the low trace element concentrations are within acceptable limits (Baize, 1997) and the organic matter percentages lower than 3 % are compatible with a high rank reuse (SETRA-LCPC, 2003). As for the 60 µm – 2 mm fractions, the 2 mm – 30 mm fractions are largely decontaminated and more specially for Lille sediments with 16 mg kg^{-1} of copper, 58 mg kg^{-1} of zinc and 2.6 % of organic matter which allow a high rank reuse. For Cheviré, in spite of an important reduction of the pollution between the bulk sediment and the 2 mm – 30 mm fraction (7.5 % organic matter versus 16 % ; 383 mg kg^{-1} of hydrocarbons versus 3540; 20 µg kg^{-1} of phenanthrene versus 388 and 650 mg kg^{-1} of zinc versus 1180), the organic matter percentage is higher than 3 % and this fraction can be only reused in case of non stringent uses.

3.3 Valorisation of the treated fractions

In the following, only the decontaminated 60 µm-2 mm fraction from the pilot plant will be considered; geotechnical tests were carried out on this fraction which was classified in different classes according to the Technical Guidelines on Embankment and Capping Layers Construction (SETRA-LCPC, 2003). In attempting to classify a soil on the basis of criteria capable of determining its suitability as fill and associated conditions for its placement, four parameters must be determined : organic matter, grain size, clay and state characteristics. Geotechnical characteristics of the different fractions are presented in Table 3.

Table 3. Geotechnical characteristics of 60 µm – 2 mm fraction

		OM %	dmax	< 2 mm	< 80 µm	VBS	ρd OPN	ρs
			mm	%	%	g 100g^{-1}	t m^{-3}	t m^{-3}
Cheviré	60 µm – 2 mm	2.5	<50	89	2	0.25	1.64	2.65
AhAh	60 µm – 2 mm	5.1	<50	-	-	-	-	-
Lyon	60 µm – 2 mm	4.5	<50	-	-	-	-	-
Lille	60 µm – 2 mm	2.8	<50	100	6	0.67	1.70	2.65

Based on these characteristics it appears that the Cheviré and Lille sediments stand in the B_2 class, i.e. clay sand. This class is sensitive to water and five subclasses are defined according to the water content. The natural moisture content (W_n) is compared with the Standard Proctor optimum moisture content (W_{OPN}) to determine the subclasses: B_2th, B_2h, B_2m, B_2s or B_2ts. For these sediments, a reuse as road or pipe embankments, or as capping layer is possible. B_2th are soils for which trafficability and compaction are very difficult and B_2ts are considered as being impossible to compact properly by standard methods. For the three other subclasses, a recovery as road embankment is possible but some requirements can be necessary as the height of the embankment, a moisture correction, a treatment with lime or another binder and the compaction conditions. A use as capping layer material is also possible for the B_2h, B_2m and B_2s subclasses. Nevertheless, these treated sediments are sensitive to water and a treatment with hydraulic binders is necessary before the recovery.

Finally, with their characteristics, the B_2 class can be reused as pipe embankment in the bottom level of embankment without treatment and requirements.
The AhAh and Lyon sediments belong to the F_{11} class; their OM content allows these sediments to be reused as embankment.
It appears, therefore, that the treated fractions can be reused in road construction, either as road embankments, capping layers or pipe embankments. Several other stormwater sediments were also treated (Pétavy and Ruban, 2007) and the results were quite satisfactory: 12 fractions among 14 can be reused.

4. CONCLUSION

This study shows that stormwater sediments, i.e. pond and street sweeping sediments, can valuably be processed by means of a physical treatment. A pilot plant based on screening and attrition was designed, which concentrates metallic and organic pollutants in the fine particles allowing to reuse the coarse, unpolluted fractions. The treated fractions are likely to be reused as road embankments, capping layers or pipe embankments. In a context of sustainable development, these treated sediments are a valuable source of material, likely to answer to the strong demand for embankments. The constant changes in environmental laws and disposal in landfills becoming more restrictive, sediment treatment by means of a mobile unit appears quite promising and competitive with regard to the solutions actually proposed (incineration, landfill).
These results are most encouraging, which lead us to collaborate with industrial partners for the development of a mobile treatment plant based on the principles of ATTRISED pilot unit. Sediment treatment is a wide problem largely exceeding stormwater and the ATTRISED process could be used for the remediation of river dredging sediments or sediments from sewer networks. Finally, the results of this innovative research could be used to prepare a technical guide aimed at helping managers with the treatment and reuse of stormwater sediments.

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