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Physical and chemical parameters in wastewater and at the water-sediment interface in sewer network

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Abstract

Sewer networks are nowadays considered as biochemical reactor and their overflows contribute to the alteration of the receiving waters. So a research project aims at improving the knowledge of solids dynamics as contributors to pollutant fluxes. Therefore, a preliminary experimental study was conducted in a combined sewer of Nantes (France), from March to August 2010, by dry weather conditions. It consisted of measurements of global parameters and concentrations of major ions, trace metals and sulphur species in wastewater but also at the interface with the sediment. The main finding was the evolution of global parameters (pH, conductivity, Eh) at the water-sediment interface in relationship with the profile of sulphur species, indicating the synthesis of hydrogen sulphide by sulfate-reducing bacteria at the interface and in relationship with the history of the deposit. Moreover the vertical gradient of trace metals is strongly related to those of total suspended solids.

Keywords: sewer deposit; flow velocity; total suspended solids; trace metals; sulfur species; water-sediment interface

INTRODUCTION

Sewer systems are real physical and biogeochemical reactors. Indeed, they are subject, first, to sedimentation and erosion and contribute, on the other hand, to the biogeochemical transformation of inorganic and organic compounds present in the wastewater (Ashley et al., 2004). The deposits have been described as being mainly constituted by three types of materials (Crabtree, 1989; Oms, 2003): coarse granular deposit, organic layer, biofilm. The dynamics of the upper part of the sediment is a key issue, as those is easily eroded and then rejected during rain events. Processes related to the mineralization of organic matter resulting in the genesis of hydrogen sulphide (H₂S) are specifically investigated as this gas is responsible for odors, corrosion networks and for safety reason (e.g. Ray Sharma et al., 2008). Apart from the sulfur species, speciation changes also affect trace metals present in wastewater. They are found mainly in particulate form and originate mostly from rainwater (Gromaire et al., 2001). Moreover, recent studies have highlighted the carrier phases of these trace metals in sediments (El Samrani et al., 2004; Houhou et al., 2009). However, even if the identification of physical parameters influencing the sediment stratification has increased (Oms, 2003), the in-sewer process need further investigations (Ashley et al., 2004) as solid transport and bio-geochemical processes are closely related.

Therefore, a preliminary experimental study was conducted in a combined sewer of Nantes (France), from March to August 2010, by dry weather conditions. It consisted of measurements of global parameters and concentrations of major ions, trace metals and sulphur species in wastewater but also at the interface with the sediment as it should help in understanding the chemical system. Physical data should also be acquired at the same time, as

the chemical equilibrium/ disequilibrium state of the sediment layer is linked to the physics of the system (Ahyerre et al., 2001).

Physical and chemical in situ measurements and analyses are therefore proposed to describe chemical profiles in the water column and at the water-sediment interface and to assess the stratification of chemical compounds. An experimental site was chosen for the measurement and sampling campaigns. The site and experimental set-up are described. The experimental results are presented and discussed.

EXPERIMENTAL SECTION

Experimental site

The experimental site is located in the combined and central part of the Nantes metropolitan network (North-western France) along the former bed of the Erdre river. The catchment area is estimated at 1.8 km² for 100 000 equivalent habitants. The sewer has a 2.2 m high egg shaped section with a bank (Fig. 1a). A 20° bend is located about 10 m upstream of the measurement point (Fig. 1b). This site presents a relatively thick muddy sediment layer. This is related to the flow relatively low velocity (about 0.10 to 0.15 m.s⁻¹). The thickness of sediment is variable as a function of the flow velocity, but also of cleaning operations. During the experimental period, the sewer was cleaned on June 23th 2010. Seven dry weather measurement campaigns and samplings were performed from March to August 2010, between 7am and 9am, including two campaigns after the cleaning of the sewer on June 23th.

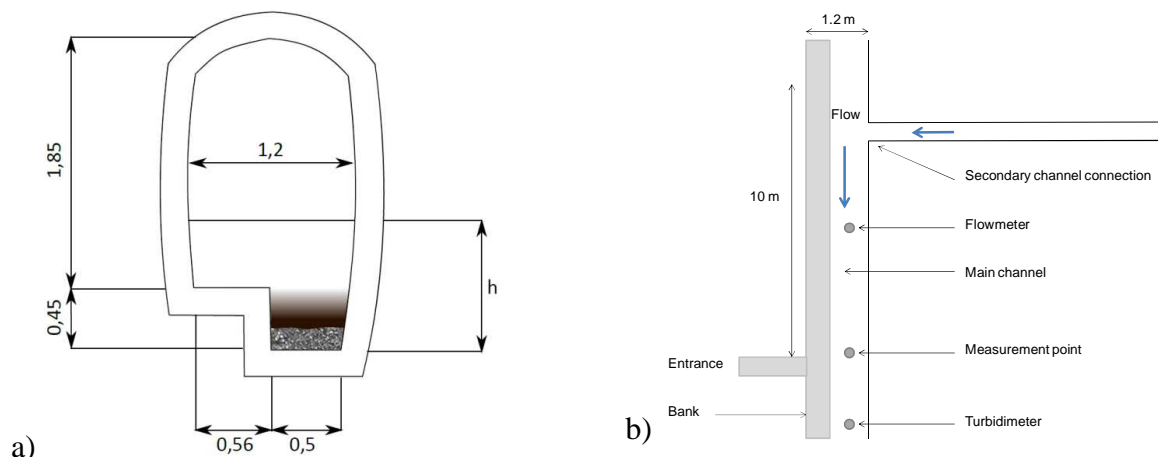


Figure 1. Experimental site : a) sewer cross section; b) scheme of the measurement area
In situ measurements and samplings

On the experimental site, measures of sediment and water height are done with a gauge. It is constituted of a plastic washer (Fig. 2a) sliding along a backing tube and stopping when it comes to sediment depth. Thus the washer is blocked and the flow meters and vertical sampler can be put on it to measure the wastewater height and velocity. During most of measurement campaigns, velocity profiles have been obtained with 3 Nivus PVM-PD flow meters that were moved vertically to scan the entire water column from the top of the washer to the free surface. Those sensors are 1 directional acoustic Doppler flow meters used to measure the velocity in the streamwise direction as explained by Larrarte (2006). At a given sampling location, the dataset included the mean value of two replicates, with each being the mean value of the instantaneous velocity gauged over a 10-second period. If the difference exceeds 0.05 m/sec, the flowmeter has to be removed from the water and cleaned. Water level

and turbidity were continuously monitored with an Isco acoustic Doppler flowmeter from May 2010. Data were recorded every 5 minutes.

Physicochemical parameters have been measured on site with a set of electrodes (pH, conductivity, temperature, redox potential) (Multi 340-I WTW) along vertical profiles. In the same manner, wastewater has been sampled by putting a 4 points vertical sampler on the washer. This sampler was composed of four vertical pipes with a 10-mm internal diameter oriented upstream. Each tube was connected to a plastic pipe extending to the bank and sampling was performed using glass vacuum bottles (Fig.2b). The water column and the water-sediment interface were sampled except when clogging occurred (Fig. 2c). The suspended solids concentration was determined for each sample. Sediments have been sampled with a shovel.

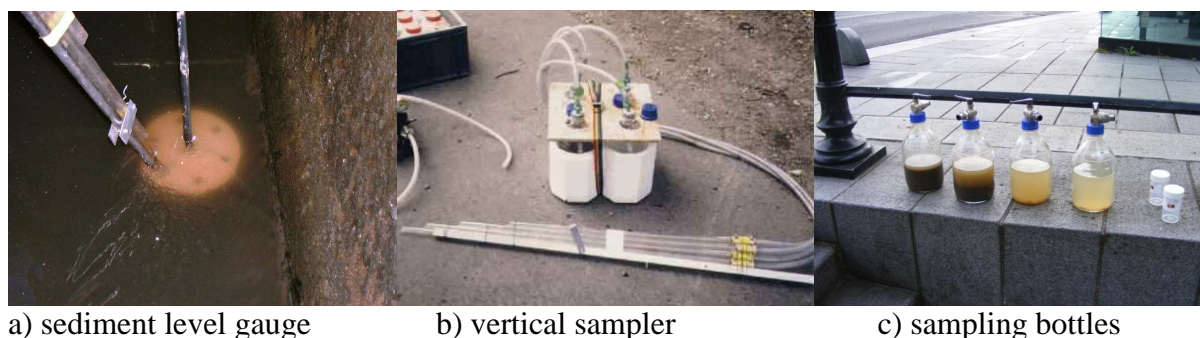


Figure 2. Experimental set-up

Physical and chemical analyses

Liquid samples were analyzed for total suspended solids (NF EN 872, 2005). They were filtered through a Millipore AP20 glass fiber filter (with a pore size of between 0.8 and 8.0 microns), and the filters were dried at 105°C for 24 hours. The mass of the residue was determined by weighing. Prior to filtration, the samples were run through a 2-mm sieve. The accuracy of this analytical process was evaluated at approximately 5% by mass, while the accuracy of the various sampling methods was determined through relative errors.

The samples were also analysed for major anions (Cl^- , PO_4^- , NO_3^-), major elements (Al, Na, Mg, Ca, K, Fe), trace elements (Pb, Zn, Ni, Cr, Cd, Cu) and sulfur species (SO_4^{2-} , S^{2-} , SO_3^{2-} , total S). Raw samples were filtrated through a 0.45- μm pore size membrane (Millipore). Dissolved concentrations of major elements and of trace metals were obtained by analysis of the filtrates of the raw samples after acidification of the filtrates at $\text{pH} < 2$ with nitric acid. Concentrations of chemical elements and trace metals in the particulate phase were obtained by digestion of the 0.45 μm filters and analysis. Total concentrations were calculated as the sum of dissolved concentrations and concentrations on particulate matter. Determination of chemical element contents was performed by Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES; Varian 720-ES). The quantification limits for Cd, Cr, Cu, Ni, Pb and Zn are respectively 0.5, 5, 2, 10, 10 and $2\mu\text{g}\cdot\text{L}^{-1}$. Anion analysis was performed by anionic chromatography on samples filtered through a 0.45- μm pore size membrane. Analysis of sulphur species was performed by a certified laboratory (IDAC, Nantes). Sediments were sieved, dried and their volumetric mass was measured.

RESULTS

Water and sediment heights, fluid velocity and TSS

The dry weather experimental measurements for the 7 campaigns are presented in Table 1. The relationship between rainfall and water level in the sewer is highlighted in Figure 3.

Table 1. Experimental conditions of the sampling days – ht : water height; hsed: sediment height; C: TSS concentration; V : at the free surface

2010	16 March	20April	11 May	26 May	18 June	7 July	4 August
ht (m)	0.76	0.68	0.58	0.59	0.62	0.54	0.42
hsed (m)	0.31	0.30	0.33	0.35	0.38	0.14	0.02
V (m.s ⁻¹)	0.18	0.13	0.09	0.18	0.14	0.14	< 0.05
C(min max) (mg.L ⁻¹)	– 219-5400	-	-	170-188	138-294	208-6719	116-3862
T _{water} (°C)	12	14.6	11.5	17.9	18.6	18.1	20

The water level shows dry weather daily patterns but also a great reactivity to rain events, as the experimental site is located on a combined network. The water level decrease after mid July is related to the fact that quite a lot of Nantes inhabitants are away from the city for the summer holidays. It can also be seen that the turbidity has an averaged value of about 400 FAU even if a lot of fluctuations can be observed.

The formation of an organic layer above the coarse granular deposition is likely to occur, because of the low values of flow velocities between 0.09 and 0.18 m.s⁻¹. This result is consistent with the findings of Ahyerre et al. (2001) and Oms (2003) on the formation of a stable layer when V is lower than 0.14 m.s⁻¹. It should be noticed that significant rainfall events in mid-June did not alter the sediment deposit. The cleaning of the sewer in late June reduced significantly the sediment height, but it seems that two increases of the water height (14/07 and 22/07) had more impact on the sediment thickness. In this case, the deposit was disturbed more easily than before the cleaning.

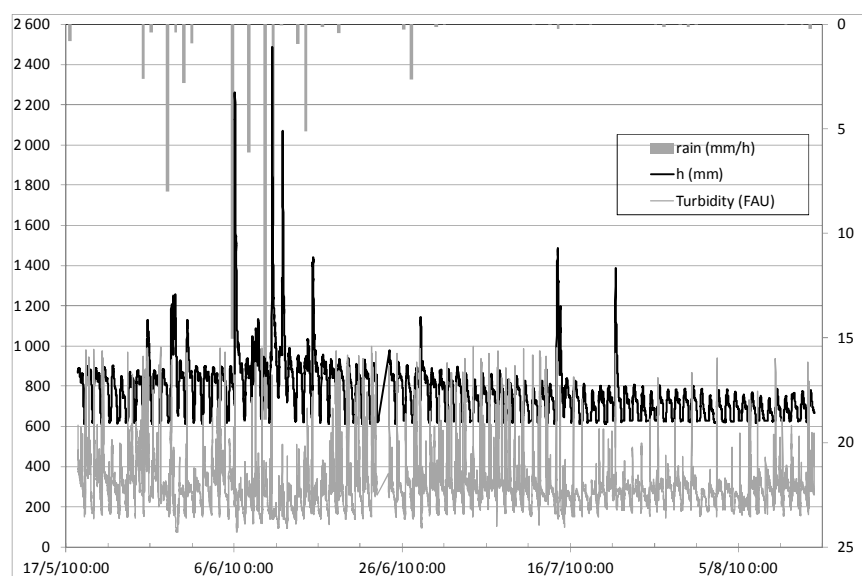


Figure 3. Continuous measurements of water height, turbidity and precipitations

Figure 4 shows the velocity and suspended solids profiles obtained during the campaigns. The flow meters and samplers were put on the washer. However some clogging problems have been observed on the sampling pipes and, very close to the top of the sediment, the flow meters were unable to give any measurement. Stratification in terms of TSS appears whatever the water height. The analyses have shown that more than 75% of the suspended solids are organic matter. The sediment had a volumetric mass of about 2000 kg.m^{-3} .

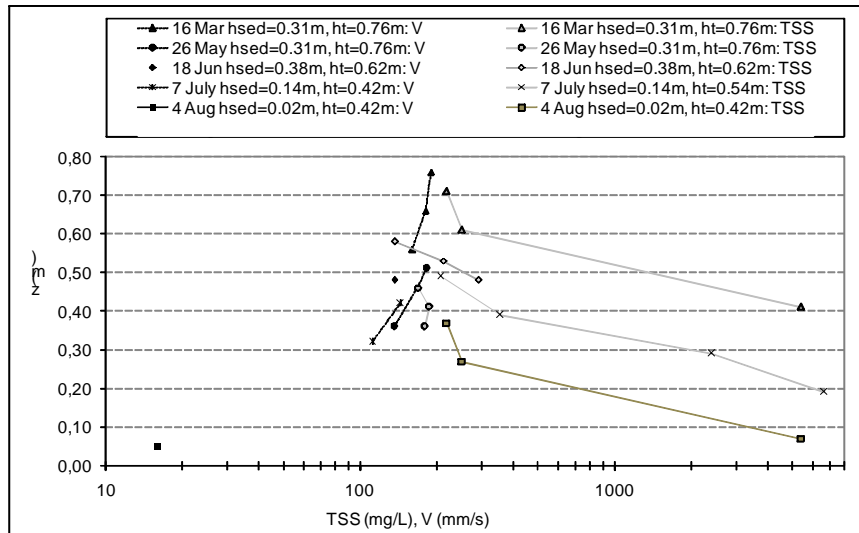


Figure 4. Velocity (V) and suspended solids (TSS) profiles

In situ chemical parameters (pH, conductivity, Eh)

The conductivity values ranged from 930 to $1100 \mu\text{S.cm}^{-1}$, with very low variation within the profiles before cleaning of the sewer (Fig.5a). They are consistent with data from the literature (Lamprea, 2009; Lebonté et al., 2007). The pH is neutral to alkaline (7-8), except after the cleaning. The redox potential (Eh) indicates a slightly reducing environment (values between -82 and 4 m.V).

It is noteworthy changes in the physicochemical profiles before (a) and after (b) cleaning of the sewer (Fig.5). When the deposit thickness remains stable, the parameters in the overlying water column are constant. When the sediment layer (coarse granular type) is very low (2 to 15 cm), an interface of about fifteen cm thick, in which there is a simultaneous increase in conductivity with decreasing pH and redox potential, set up in the water column. pH values between 5 and 6 in the bottom of the profile are comparable to that which can be measured in water saturated sands.

Major elements, trace metals and sulfur species

Concentrations of chloride, phosphate and major elements (Ca, Na, K, Mg) are of the same order of magnitude as those of the literature (Lebonté et al., 2007; Houhou et al., 2009 b). They vary little along the profile, from the free surface to the coarse granular type sediment, with low deviations from the mean values of 1 to 7%. No stratification was observed for these elements present as dissolved species.

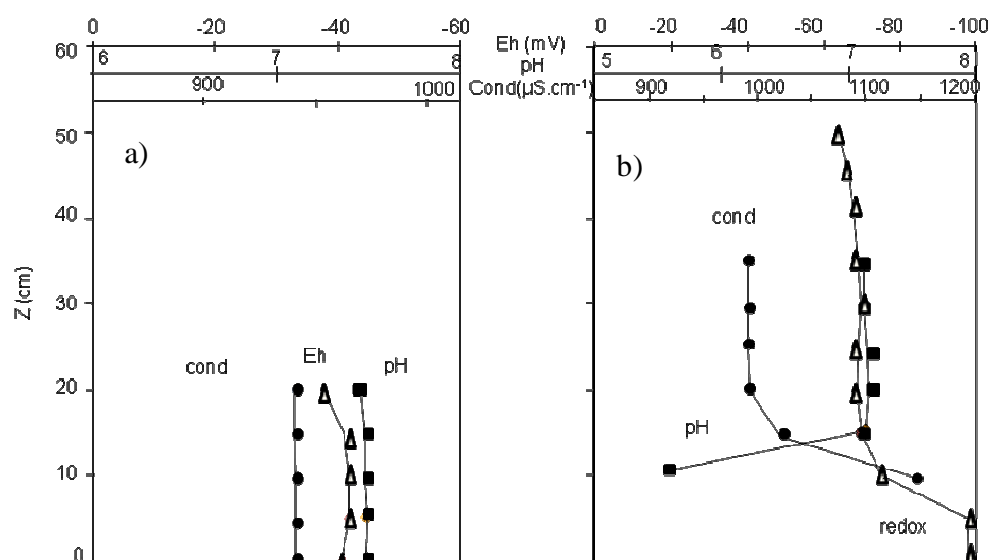


Figure 5. Physicochemical parameters profiles (conductivity, redox potential, pH)– “Z=0 cm”: top of the coarse granular type sediment a) before the cleaning of the sewer on June 23th 2010; b) after the cleaning

Al and Fe are mainly present in particulate phase and their concentration follows that of TSS. This result is consistent with the presence of these elements either in minerals or in heavy-metal-bearing particles (Houhou et al., 2009). Trace metals total concentrations (Cu, Pb, Zn, Cd) can be compared to values measured in sewer of historic district of Paris (Kafi et al., 2008) (Table 2). The variability of the values is high, whatever the phases (dissolved or particulate). Except for Ni, the trace metals are mainly in particulate phases. An increase of the concentrations is observed as TSS increase near the coarse granular sediment. Because of low concentrations in the dissolved phase and low number of samples, it is difficult to draw conclusions about the stratification of dissolved species. However, for Zn, a significant decrease of dissolved concentration is observed at the water-sediment interface from 150-400 to 50 $\mu\text{g.l}^{-1}$. Precipitation of neoformed mineral phases containing Zn could be responsible for this decrease (Houhou et al., 2009).

Table 2. Anions, major elements and trace metals concentrations and physical speciation (P: particulate, D: dissolved)

Chemical species (mg.L ⁻¹)	min	max	Physical speciation (% P, D)	Chemical species ($\mu\text{g.L}^{-1}$)	min	max	Physical speciation (% P)
Cl ⁻	50	80	-	Cd	<1.q.	1.5	
PO ₄ ³⁻	8	10	-	Cu	96.9	149.2	85-95
Al	0.5	2.2	98-100 (P)	Cr	7.6	15.8	70-100
Fe	0.8	1.6	83-92 (P)	Ni	17	52.7	30-70
Ca	49.4	64.9	90-99(D)	Pb	15.7	43	100
Na	0.1	70		Zn	228.6	762	70-90
K	7	13					
Mg	7	9					

Figure 6 illustrated the difference of sulfur species profiles before (a) and after (b) the sewer deposit has been cleaned. Total sulfur concentrations are very close above 20 cm between the two states of the system but main chemical processes occur in a transition zone (water-sediment interface), as already described for the global parameters (Fig.5). Before cleaning, the system seems to be fairly balanced. The sulfide concentration is very low and the sulfate concentration is close to the total sulfur concentration. After cleaning, the sulfide concentration increased strongly and the sulfate concentration decreased at the water-sediment interface. These results are indicative of the activity of sulfate-reducing bacteria in the system after cleaning. The transformation of sulfates to sulfides leads to a reducing environment, which is consistent with the measured redox potential.

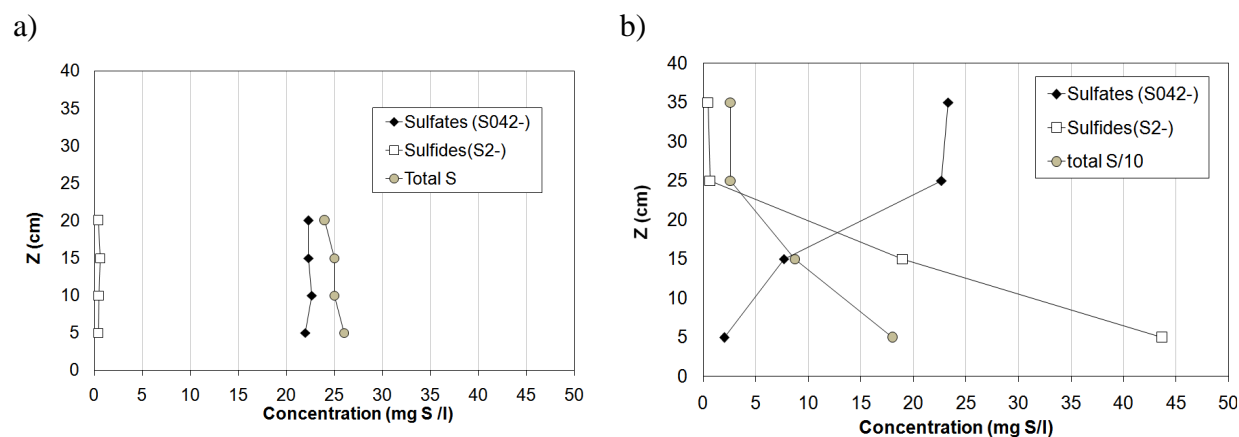


Figure 6. Sulfur profiles – “Z=0 cm”: top of the coarse granular type sediment a) before the cleaning of the sewer on June 23th 2010; b) after the cleaning

CONCLUSION

In this study in a combined sewer of Nantes, the methodology is based on on-site measurements and laboratory analysis to observe the vertical variability of parameters and concentrations of chemical species in wastewater and at the water-sediment interface. Cleaning operation during the experimental period has highlighted that during the re-deposition of the sediment, degradation of sulfur species was activated in relationship to the variation of global parameters, contrary to what was observed in the “steady state system” before cleaning. The variation in the suspended solids concentration was low in the upper water column but can increase by a factor of 20 to 35 when the sample is collected at the interface. As trace metals are mainly in particulate phases, their vertical gradient of concentration was related to those of TSS. The concentrations of dissolved species (major ions, anions, trace metals) did not vary significantly within the profiles, except for Zn. These ions remained between 90 and 99% in dissolved form. This study highlighted the need to couple techniques of observation the water-sediment interface and sampling and analyses of pore water in fluid layer and coarse granular type deposit.

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