Suspended particles in wastewater : acoustical characterization and modeling

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Wastewater regulation and treatment is still a major concern in planetary pollution management. Some pollutants, referred to as particulate matter, consist of very small particles just suspended in the water. Various techniques are used for the suspended particles survey. Few of them are able to provide real-time data. The development of new, real time instruments needs the confrontation with real wastewater. Due to the instability of wastewater, its modeling in terms of suspended solids was performed. Hence, its sedimentation and acoustical behaviour was studied and modelled on an artificial matrix.

Knowing the description of real wastewater, we tried to produce an artificial mixture made of basic ingredients. A good agreement in terms of turbidity and settling velocity was observed between the artificial wastewater matrix and the real one. After a brief outline of the self-developed multi-frequency fluxmeter, this paper will investigate the individual contribution of the different compounds to the acoustical signal. A good comparison of acoustical and turbidity behaviour of wastewater will thus be obtained.

Keywords: acoustic, suspended solids, settling velocity

1 INTRODUCTION

Environmental protection became a major concern in many countries. One of its aspects is wastewater management. As for regulation of industrial processes, sewage supervision needs real time flow control.

Urban wastewaters are a complex medium with variable characteristics. Currently, the suspended particles concentration in wastewater is either measured through sampling either through turbidity. The major drawback of the first method is the time delay between the sampling and the measurement which forbids any real time retroaction on the water regulation. On the other side, turbidity measurements might be biased by a punctual modification of the granulometric repartition of total suspended solids (TSS), by a variation of the particle type or by the presence of a dye, factors which all lead to a change of the turbidity/concentration relationship. The major hindrance for the use of ultrasound concentration measurements in wastewater is the huge variety of encountered materials in various proportions. Within the common particles found in wastewater, only sands have been exhaustively studied by acoustics. Preliminary work on various materials like paper pulp, loess, garden earth, soups and excrements was carried out. It showed that none of these materials has an identical behavior to sand. Anyhow, the analysis of the ultrasonic spectrum in terms of size distribution, based on the known behavior of sand, reflects at least qualitatively the real evolution of particle size. For example, by sifting garden earth (which is a mixture of organic and mineral particles) through larger sieves, the ultrasonic spectrum analysis shows a growth of the mean diameter of particles.

Note that the aim of our work is not the exact decryption of the acoustical behavior of wastewater particles. This would need the production of calibrated particles of natural materials for which even the size notion is often problematic (like for example for fibers at different flocculation levels). On a semi-empirical basis, our aim is to build reliable indicators of the TSS evolution relying on the acoustical spectrum without or as less as possible calibration steps.

2 SUSPENDED SOLIDS CONCENTRATION MEASUREMENTS

2.1 Standard methods

Different techniques were used to measure the suspended solids concentration.

A first technique is the time dependant collection of wastewater samples. After sampling, the water is filtered on a 1 µm filter and the TSS concentration is calculated from the solid depot on the filter after evaporation.

An estimate of total suspended solids can also be obtained by an optical measurement known as turbidity. The correlation between the turbidity and the TSS concentration will hold only for the particular wastewater from which it was derived. A

HACH turbidimeter was used for the nephelometric turbidity measurements of wastewater and artificial matrix.

2.2 Acoustic investigation

The acoustic characterization was done with a self-developed multi-frequency fluxmeter [1]. This instrument allows the measurement of the concentration of several size classes of suspended particles (see figure 1).

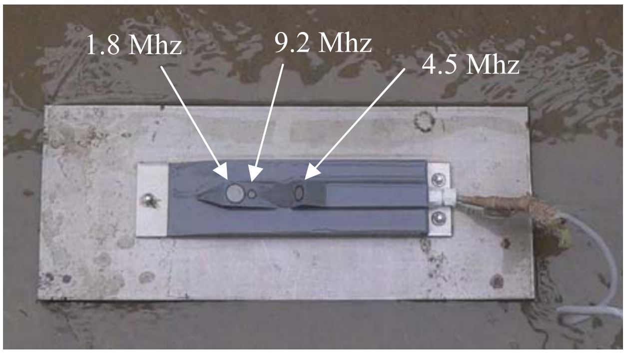

Figure 1: Our multi-frequency fluxmeter.

The acoustic signal can be expressed in terms of :

$$T_j(r) = \beta_{p,j}(r)\exp\left[-4\int_0^r \alpha_{p,j}(r)dr\right] \quad (1)$$

T_j stands for the acoustic backscattered signal at frequency j. The acoustic backscattering and attenuation coefficients for each particle type p are respectively $\beta_{p,j}$ and $\alpha_{p,i}$ both depending on frequency. We assume that the particle distribution, independently of their size, is uniform along the beam. Thus, there's no distance dependency of the backscattering and attenuation coefficients. However, the attenuation coefficient is usually a small value. Hence, its estimation error might be huge in regard to its mean value. Thus, only the acoustic spectra obtained for frequencies above 6 MHz give significant attenuation information. In its current configuration, our instrument gives only a single exploitable profile for attenuation at 11.7 MHz.

Another assumption is an identical size distribution of all particles whatever the value of their density is. On the basis of the semi-empirical formulae describing the behaviour of sand, the backscattering coefficient becomes :

$$\beta_{p,j} = \frac{C_m}{\rho_{mean}}\sum_{i=1}^{n} F_{j,i}\gamma_i \quad (2)$$

where C_m stands for the total massic concentration in kg/m^3. The mean density of all particles is ρ_{mean} and γ_i stands for the fraction of the ith size class. The mean value $F_{j,i,}$ of the ratio of the form function by the particle radius over 5 diameter classes (12, 30, 70, 170 et 400 µm) is given by the following expression where a_s is the particle radius :

$$F_{j,i} = \left\langle \frac{f_{j,\infty}^2}{a_s} \right\rangle_i \quad (3)$$

The form function itself is calculated from [2,3,4] :

$$f_{\infty,j} = C_0\left(\frac{1.1x^2}{1+1.1x^2}\right) \text{ with } x = k_j a_s = \frac{2\pi}{\lambda_j}a_s$$

$$C_0 = 1.1\left[1-0.25e^{\left(-((x-1.4)/0.5)^2\right)}\right]\left[1+0.37e^{\left(-((x-2.8)/2.2)^2\right)}\right] \quad (4)$$

From there, the granulometric distributions and the massic concentrations of suspended particles are estimated. A second step in the data analysis is the use of the attenuation data. The attenuation coefficient can be written :

$$\alpha_{p,j} = \frac{C_m}{\rho_{mean}}\sum_{i=1}^{n} A_{j,i}\gamma_i \quad (5)$$

The mean massic attenuation factor can be expressed in a similar way as previously:

$$A_{j,i} = \left\langle \frac{3\chi_j}{4a_s} \right\rangle_i \quad (6)$$

As for backscattering, a common model exists for the normalized total scattering section χ_j. Under the same assumption as previously that wastewater suspended solids behave as sand, its value might be obtained through the modified high-pass model [2,3,5] for attenuation under its usual form :

$$\chi_j = \frac{1.1(4/3)0.18x^4}{1+1.3x^2+(4/3)0.18x^4} \quad (7)$$

On this basis, the attenuation is recalculated and compared to the one obtained by analysis of experimental data through the T_j equation (1).

3 WASTEWATER CHARACTERISTICS

Wastewaters are usually the combination of industrial and urban effluents. Their composition is variable, function of the time of the day (reflects human habits and weather conditions), of their localisation (urbanised, commercial or industrial zone). Wasterwaters were studied on two sites : the wastewater treatment plant of Greater Nancy (1) and in the sewer of the city of Nantes (2).

For the site (1), the average turbidity value is 150 NTU and the usual acoustic coefficients are 0.08 for backscattering and 0.8 for attenuation. These values are comparable to the one observed on site (2).

3.1 Sampling study

It is well known that the amount of suspended solids varies with time and localisation. However, as shown by figure 2, the mean suspended solids concentration value is 150 mg/l. The associated granulometry is known to be mostly > 150 µm.

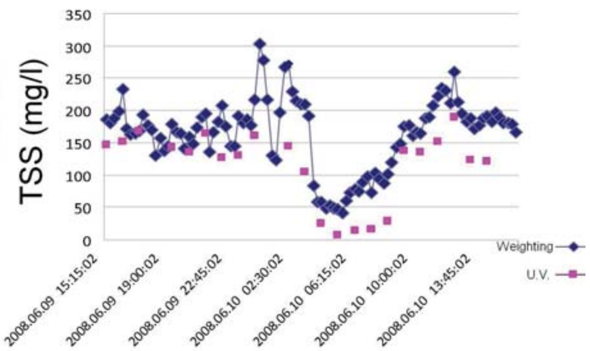

Figure 2: Total suspended solids concentration evolution as a function of time on site (1).

We tried to build our artificial wastewater matrix according to these mean concentration and size distribution.

3.2 Turbidity and acoustical behaviour study

As above for sampling, as can be seen on figure 3, the turbidity and the acoustical behaviour of wastewater are a function of time, reflecting human activities and weather conditions. On this other measurement site (2), turbidity and acoustic measurements were compared to the TSS concentration measured by sampling and show that there is a direct link between the measured data and the total suspended solids concentration. The mean value of TSS is 220 mg/l on this second site.

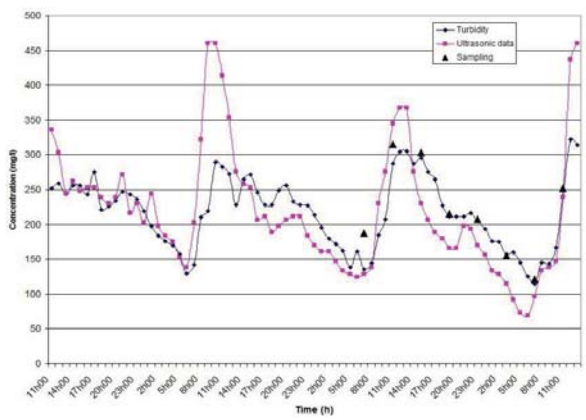

Figure 3: Total suspended solids concentration as a function of time and of measurement technique on site (2).

4 ARTIFICIAL WASTEWATER MIXTURE

Knowing the description of real wastewater, we tried to produce an artificial mixture made of simple ingredients like various kind of starches (corn, wheat, rice, potatoe) and toilet paper. To reflect the trouble aspect of wastewater due to the organic matter, an alcohol-free pastis was also added to the mixture. The granulometry of the various compounds was measured by microscope and is mentioned in table 2.

4.1 Turbidity

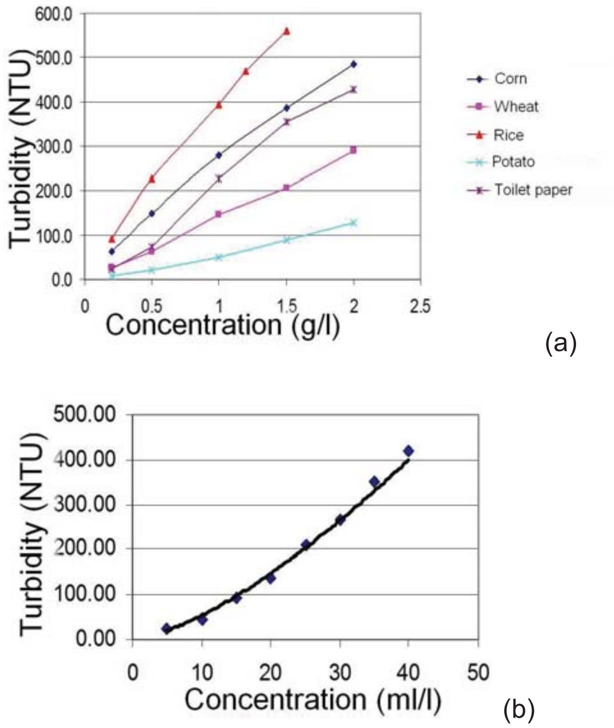

Figure 4: Turbidity evolution as a function of concentration and compound, (a) Various starches, (b) Pastis.

As can be seen on figure 4, turbidity is a roughly linear function of the ingredient concentration for all the starches and the toilet paper and is a power function of the pastis concentration.

Table 1 summarizes the turbidity behavior of the various ingredients :

Compounds	Turbidity (NTU)
Potato starch	60 * concentration (g/l)
Wheat starch	140 * concentration (g/l)
Toilet paper	220 * concentration (g/l)
Corn starch	250 * concentration (g/l)
Rice starch	340 * concentration (g/l)
Pastis	1.90 * concentration (g/l)
Wastewater	50 to 300 NTU

4.2 Settling velocity

The knowledge of the wastewater settling velocity is of major concern for the clarifiers in wastewater treatment plants [6]. The settling velocity is an indirect reflection of the TSS composition and concentration. The standardized VICAS protocol [7] was used on our samples.

Keeping in mind the mean turbidity value, several mixtures were created in order to reproduce the sedimentation velocity of real wastewater. Figure 5 shows the individual sedimentation velocities and the sedimentation velocity of two mixtures compared to the one of natural wastewater.

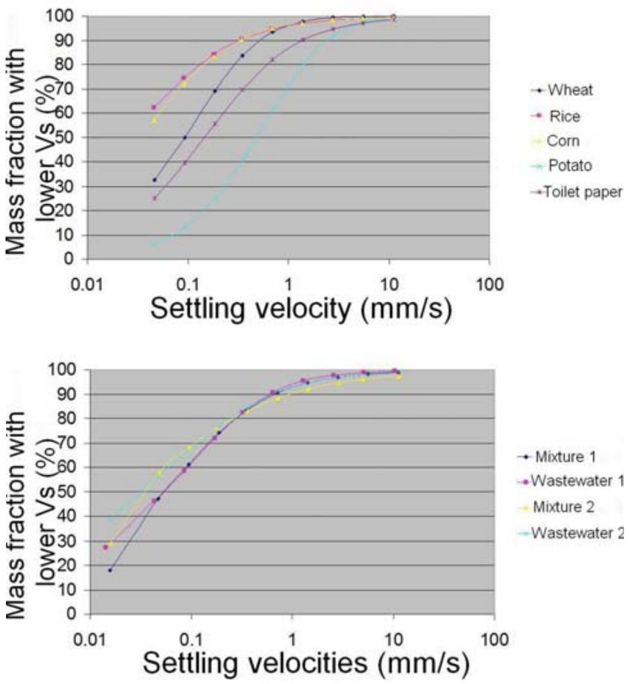

Figure 5: Settling velocities distributions, (a) Individual starches, (b) Natural and artificial wastewater.

A good agreement in terms of turbidity and settling velocity can be seen between the artificial wastewater matrix and the natural one.

4.3 Acoustical behavior

The acoustical behavior as yet only been evaluated on natural wastewater and the individual mixture components. Table 2 summarizes the results on granulometry and acoustic coefficients.

Data was obtained by multi-frequency measurements on various concentrations of each compound.

Table 2: Summary of optical and acoustical measurements

	Diameter by microscope (µm)	Diameter by US (µm)	Supposed density	β_p	α_p
Wastewaters	20 – 500	90	1.03	0.08	0.80
Potato starch	36 – 126	37	1.20	0.27	0.95
Wheat starch	18 – 72	22	1.20	0.12	0.81
Corn starch	14 – 36	16	1.20	0.11	1.14
Rice starch	6 – 18	16	1.20	0.08	1.08
Sand		145	2.60	0.28	0.32
Toilet paper		39	1.03	0.08	1.90
Alumina		19	2.4	3.38	6.26

The acoustic coefficients are expressed as mass response rate which allows the comparison of the different compounds. The mass response rate is the ratio of the diffused or attenuated intensity for a given particle type by the diffused or attenuated intensity for spherical particles of same size, of density 1 and having a form function identical to the one of sand. The corn, wheat and rice starch have acoustic coefficients close to the one of real wastewater. However, only a small fraction of wastewater suspended solids are as small. As already determined by other measurements, they might remain quite unseen by ultrasound. The toilet paper has an acoustic backscattering coefficient close to the one of wastewater but a much larger attenuation coefficient.

The coefficient of the sand are expected however the backscattering value is smaller as announced by theory. Alumina is quite “exotic” on the ultrasonic point of view, with huge backscattering and attenuation coefficients.

5 CONCLUSIONS

The size estimation given by the fluxmeter is comparable to the size distributions measured by microscope for each mixture. Thus, the average diameter extrapolating method from acoustic data gives encouraging results. However, the basic compounds with a combination of ultrasonic "reflection coefficient / attenuation coefficient" close to that of wastewater have an average diameter much smaller than the one of wastewater : a simple mixture of those compounds won’t describe the behavior of the wastewater.

Future work will be to analyze the acoustic response of mixtures mainly made of toilet paper (fibrous form) and potato starch (interesting diameter). These solutions should give an acoustic response close to wastewater and thus provide a stable and reproducible wastewater model for various laboratory experiments.

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