Suspended solids and attenuation of ultrasonic beams

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Acoustic flow-meters are gauging devices commonly used in urban hydrology. Many of them are based on the Doppler principle and their use is based on the hypothesis that the velocity of suspended particles is equal to the flow velocity. Thus, at least a small amount of backscattering particles (or bubbles) is required for the use of acoustic Doppler velocimeters. In the same time, due to thermal conduction and viscosity effects, the intensity of an ultrasonic wave propagating in an homogeneous medium decreases. In suspensions an additional attenuation due to scattering and absorbtion by particles contribute to intensity decay. This term depends on the particles nature and concentration. There is a complete lack of data for runoff and wastewaters. Moreover the density of the particles ranges between 1.03 and 1.3 and their granulometry is roughly known,… In order to quantify the attenuation by wastewaters solids, an experimental set-up has been developed. The attenuation measurement for various types of particles is presented.

Keywords: : ultrasonics, suspended solids, instrumentation

1 INTRODUCTION

Flow measurement accuracy is a major concern in waste water management. Acoustic flow-meters are gauging devices commonly used in urban hydrology [1]. The Doppler principle, mostly used for these devices, assumes that the velocity of suspended particles is equal to the flow velocity. Thus, at least a small amount of backscattering particles (or bubbles) is required for the use of acoustic Doppler velocimeters. In the same time, due to thermal conduction and viscosity effects, the intensity of an ultrasonic wave propagating in an homogeneous medium decreases .In particles laden flows an additional attenuation due to scattering and absorption by particles contribute to intensity decay. This term depends on the particles nature and concentration. There is a complete lack of data for runoff and wastewaters which density, granulometry, nature are roughly known,… An experimental study has been conducted to quantify the attenuation effect different kinds of particles. A set-up was specifically developed. It is presented before the results obtained with various kinds of particles. Then, it is now possible to estimate the attenuation parameters.

2 THEORY

The tension U received by an ultrasonic transducer located in front of another one at a distance r can be written in far-field :

$$U(r) = U_o \frac{K}{r} e^{-\alpha r} \tag{1.}$$

where K depends on electro-acoustics properties of the transducers, U_0 is the emission tension, r is the distance between the two transducers, α is the attenuation factor such as $\alpha = \alpha_w + \alpha_p$ with α_w the clear water factor and α_p the particles factor. The term 1/r arises from the spherical divergence of the ultrasonic beam in far-field .

Particle attenuation factor can easily be isolated from others intensity decay factors by using :

$$Ln\left(\frac{U_{with\ particles}(r)}{U_{without\ particles}(r)}\right) = -\alpha_p \quad r \tag{2}$$

For spherical particles of radius a, the attenuation coefficient is expressed as following:

$$\alpha_p = \frac{3\chi}{4a}\frac{C_m}{\rho_p} \tag{3}$$

where Cm is the concentration in kg.m^{-3} and the mass per volume ratio in kg.m^{-3}.

A literature review shows that, by fitting experimental results, a relatively simple expression of coefficient χ has been established for sand rigid particles [2]:

$$\chi = \frac{4}{3}\frac{1.1k_\alpha x^4}{1 + 1.3x^2 + 4/3k_\alpha x^4} \tag{4}$$

with k_α=0.18 and x=2πa/λ. where a is the particles radius and λ the wave length The ultrasounds celerity into water is equal to 1480 m/s at 20° C.

The attenuation coefficient of a mixture of n classes of particles is then calculated by:

$$\alpha_p = \sum_{1}^{n} \alpha_{p,i} \quad (5).$$

Let's consider various mixtures of particles having attenuation behaviour similar to sand and a density corresponding to suspended solids commonly encountered in wastewater d=1.03. It can be seen that this estimated attenuation at a frequency of 0.5 MHz is in any case very low (Table 2). It corresponds in worst case to a tension decay of about 3.6% at a distance of 1 meter .This estimated attenuation has to be compared to tension decay resulting from the spherical divergence of the ultrasonic beam of the order of 70 % at the same distance.

Table 1 : Particles diameters

Name	P1	P2	P3	P4	P5	P6	P7
Diameter (microns)	50	75	100	125	500	1000	2000

Table 2 : Attenuation coefficient of various particle mixtures

Mixture	Composition	$\alpha_p(m^{-1})$
M1	100 P1+ 100 P5 = 200 mg/l	$4.5\ 10^{-3}$
M2	300P1 + 200 P2 + 100 P3 + 100 P4 + 100 P5 = 800 mg/l	$4.7\ 10^{-3}$
M3	100 P1 + 50 P6 + 50 P7 = 200 mg/l	$1.7\ 10^{-2}$
M4	200 P5 = 200 mg/l	$9\ 10^{-3}$
M5	200 P6 = 200 mg/l	$3.6\ 10^{-2}$

For a Doppler flowmeter, the important data is the backscattered tension :

$$U(r, C_m) = U_0 K^2 K_1 f(r) \sqrt{C_m} \exp(-2\beta_m \frac{C_m}{\rho_p} r) \quad (6)$$

where r is the distance between the transducer and the particle, β_m the mean value of β for a given granulometric distribution, f(r) a function depending on the distance. The coefficient K is the same than in equation (1). The coefficient K_1 depends upon the particles characteristics in term of density, size or acoustic impedance. As we focus in the present paper on attenuation effects, the evolutions of this retro diffusion coefficient are not taken into account in what follows. At a given distance and a given particle size distribution the tension exhibits a maximum in function of concentration. This maximum is found at a concentration:

$$C_m = \frac{\rho}{4\beta_{moy} r} \quad (7)$$

Figure 1 shows the theoretical tension evolutions in function of concentration at a distance of 1m under various conditions in term of frequency and particle diameter. As can be seen at a frequency of 0.5 MHz and for a particle size distribution commonly encountered in waste waters, attenuation has little influence up to 5000 mg/l . Under the usual conditions of use of the flow-meters average particle diameter is to be at least 1mm for attenuation to cause a substantial decrease of the backscattered tension. Note that we estimate in the present paper the attenuation by solid particles. In case of large bubble concentration a much higher attenuation coefficient is to be expected.

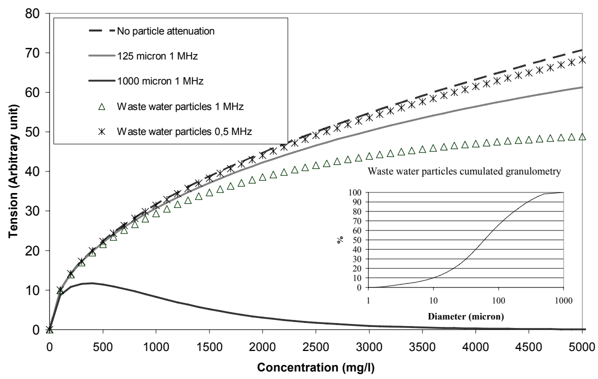

Figure 1 : evolution of the backscattered tension for particles of density 1.03

3 EXPERIMENTAL SET-UP

Industrial acoustic Doppler flowmeters designed for operating in real networks are inconvenient devices for our purpose because the signal can not be trig and monitored. Then a set-up has been built (figure 2), it is made of:

A Plexiglass water column with an height of 1.3 m and a diameter of 0.24 m. The height of the column was defined by reference to technical characteristics of flowmeters [3]:

- Two piezoelectric transducers which frequency is 0.5 MHz. This frequency is among those commonly used in wastewaters acoustic Doppler flowmeters . The emitter is located at the bottom of the column, the receiver is moved vertically with a metallic rod,
- A micro-table that controls the receiver position with 0.5 μm alignment accuracy,
- A frequency generator provides the emission tension
- An numerical oscilloscope that allows :

- To visualize the emitted and received waves,
- To measure the frequency, transit time and amplitude of the ultrasonic waves
- To record those data.

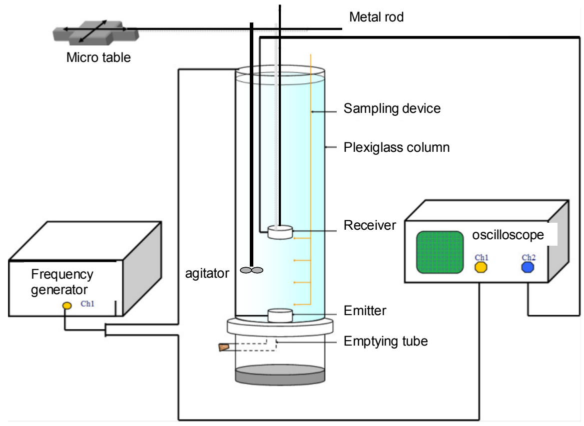

Figure 2: Experimental set-up

For each experiment, the column is full of clear water and the received intensity is measured at given distances between the emitter and the receiver. Then two experimental procedures where used following the nature of particle:

- dry sediments are melt to clear water and the received intensity is measured at given distances between the emitter and the receiver. The concentration is increased from 250 to 1000 mg.L^{-1} corresponding to usual range of suspended solids concentrations in waste-waters,
- Raw waste-water is poured into the column after removing clear water and the received intensity is measured

4 RESULTS

Basin sediment

The sediment was sampled in a retention-infiltration basin receiving highway runoff of the main bridge, close to Nantes (France). Opened in 1991, the Cheviré bridge supports on present time an average daily traffic of 90000 vehicles, with 8% of trucks. The sediment comes in the form of aggregates composed of mineral phases (quartz, feldspaths) and organic matters, deeply mixed. [4] has measured the sediment granulometry in three locations (Table 3) and determined that the x% of the particles are smaller than dX. About 80% of the particles are smaller than 100 microns. The density is equal to 2.33.

Figure 3 shows the evolution of the ratio of the received tension by the emitted tension at a distance r between the two transducers. The ratio decreases with the distance but the influence of the sediment concentration remains negligible. The intensity decay is mainly due to the spherical divergence of the ultrasonic beam.

Table 3 : Cheviré basin sediment granulometry

	D10 microns	D50 microns	D90 microns	< 100 microns
Cheviré entrance	7,40	37,40	193,40	0,80
Cheviré middle	5,00	27,20	997,30	0,79
Cheviré exit	3,90	24,00	611,90	0,83
Mean value	5,43	29,53	600,87	0,81

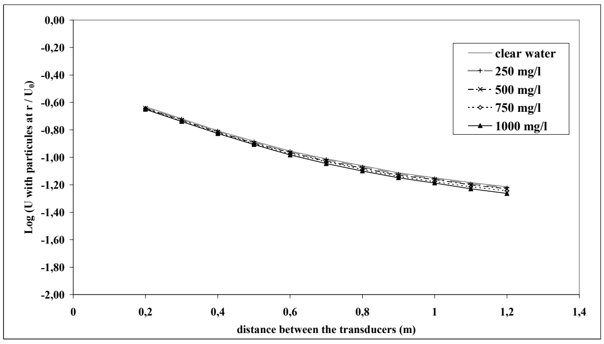

Figure 3 : Evolution of the tensions ratio with the distance between the transducers for pond sediment.

Figure 4 shows the evolution of the ratio of the received tension at a given concentration by the received tension in clear water at the same distance r between the two transducers. The evolution can be represented for example by an exp(-0,05 r) function at 750 mg/l. The attenuation coefficient α can therefore be estimated at 0.05 m^{-1}. Note that the tension decrease at low distance can not be attributed to attenuation in the bulk of fluid and reveals rather the settling of a few particles on the lower transducer. In consequence the attenuation coefficient is probably overestimated. Generally speaking this phenomenon of particle settling on the transducer is much more likely to cause a decrease of velocimeter range than attenuation in the bulk of fluid.

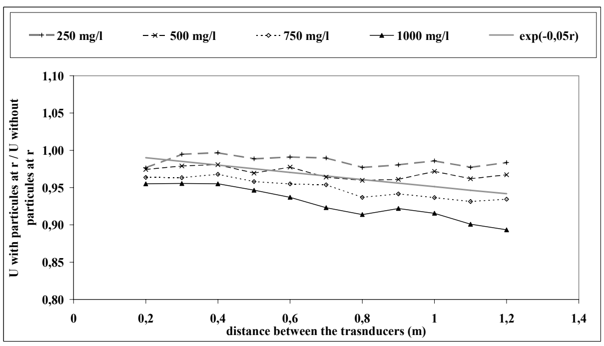

Fig. 4: evolution of the ratio of the received tension at a

given concentration by the received tension in clear water.

Waste waters

The sampling point is located in the urban combined network of Nantes (north-western part of France). All the waste waters of the northern part of the urban district are transported there, that means the effluents from the area with 600,000 equivalent-inhabitants.

Figure 5 shows the evolution of the ratio of the received tension by the emitted tension at a distance r between the two transducers. The ratio decreases with the distance but the influence of the sediment concentration remains negligible.

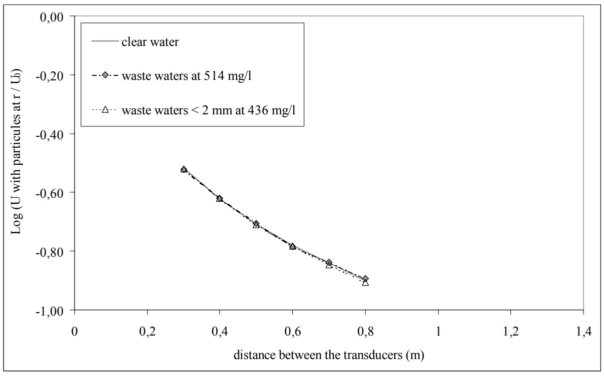

Figure 5 : Evolution of the tensions ratio with the distance between the transducers waste-waters.

Figure 7 shows the evolution of the ratio of the received tension at a given concentration by the received tension in clear water at the same distance r between the two transducers. There is not any decay of the ratio that means that the attenuation coefficient can be taken equal to zero. In other words the attenuation of the ultrasonic beams by the particles in suspension within the wastewaters, at the common wastewaters concentrations, is negligible. Those results correspond to those of [5, 6].

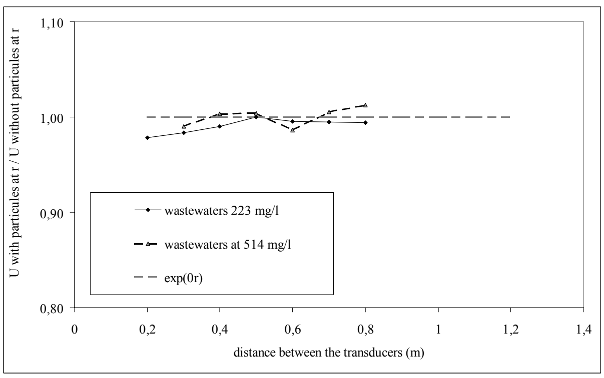

Figure 6 : evolution of the ratio of the received tension at a given concentration by the received tension in clear water.

5 CONCLUSIONS

Due to diffusion, the intensity of an ultrasonic wave propagating in a suspension of solid particles within water decreases. The order of magnitude of this decrease has been estimated theoretically for particles having the same attenuation behavior than sand and proved to be negligible.

The experimental investigation has shown that pond sediment are slightly attenuating the propagation of ultrasonic beams. On the other hand, the attenuation of the ultrasonic beams by the particles in suspension within the wastewaters, at the common wastewaters concentrations, is negligible. And then those particles are not influencing the range of the flow meters. In cases when a decrease of the velocimeter range is actually observed it as rather to be attributed to particle settlement on the transducer or to a high bubble concentration in the flow .

ACKNOWLEDGEMENT

The authors wish to acknowledge Jean-Pierre Legendre, technician at the Water & Environment Department of the Laboratoire Central des Ponts et Chaussées, for his valuable contribution to this project.

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