International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

Ultrasonic Measurements Of Attenuation And Velocity In Clay Suspensions: Application To Characterize The Dam Water

A. Hamine, B. Faiz, A. Moudden
[1,2]*Laboratoire de métrologie et de traitement de l’information, université Ibn Zohr,*
Faculté des sciences, 80000 Agadir, Morocco
[3]*Ecole supérieure de technologie d’Agadir, Morocco (ESTA)*

Abstract

The propagation of ultrasonic waves in dilute clay suspension is strongly affected by the diffusion of the wave by the clay grains. The mean diameter of the clay particles is around 10µm of magnitude of the acoustic wavelength in distilled water. Then the diffusion is so resonant and the mixture is the seat of multiple scattering. Experimental investigation, carried out on different clay suspensions is based on the measurement of velocity and attenuation of the coherent wave at different frequencies. The propagation studies are particularly focused on the measurement of attenuation and velocity. In the first part, we clarify the validity of this method in the study of a known homogeneous medium: distilled water. The second part is devoted to the propagation of waves in clay suspensions with different concentrations. We have shown that when we increase the frequency of the transducer this significantly increases the speed of sedimentation of clay grains, but this only in the case of dilute suspensions. The study of two frequencies ranges is shared by an area of resonance scattering, characterized by a high attenuation and dispersion of the ultrasonic velocity.

1. Introduction

The dilute suspensions of suspended solids (SS), are widely known in several fields of engineering, such as civil engineering, food and pharmaceutical industries, [1-2]. These particle-fluid mixtures are omnipresent in geophysical situations such as debris flows, sediment transport, underwater avalanches and dams. The major elements responsible for the trouble of the water dam during floods are primarily SS, clays and sands transported by river water. Sludge and clay transported to the dam during floods are composed of fine sand and clay particles of even smaller dimensions, their sedimentation even in calm water is very slow. The possibilities of sedimentation are also related to the average particles size. The clays grains can be transported to the dead area as dams, tanks and lakes where the sedimentation is not easy, or transported directly to the sea where they are producing their flocculation and sedimentation after reacting with electrolytes. The sedimented clays cluttering the estuaries of rivers and dams water, reducing the hydraulic energy. The quantity transported of clays affects the life of the tanks designed for energy production. A dam traps sediment that would normally be carried upstream water treatment stations and decreases the size of the tank, so its capacity for energy production. It is necessary to know the amount quantities of clays downstream to design effective and long-term of tanks. The dam water contains different sizes of clay grains. Often considerable amounts quantities of clay block the tanks and pipelines located in the treatment stations. The agents of stations doing several chemical tests every hour to check the concentrations of clay in the water station. These tests will be used subsequently to optimize the addition of chemicals that allow to recovery the clay grains.

1.1. Background and motivation

Our study is limited to the laboratory scale and it consists to monitor in real time the sedimentation of suspended solids (clay grains) by measuring the attenuation and phase velocity of sound in different mixtures. The knowledge of the mechanism of sedimentation of particles and their interactions in two-phases of mixtures gives the level of interest, both in scientific terms and in terms of applications. That’s means access to parameters such as concentration, turbidity, attenuation and ultrasonic velocity in each suspension. The real-time monitoring of these parameters will allow us to optimize the addition of chemicals (coagulants) that allow the recovery of clay. In other ways, the fundamental problem is to determine the physical and chemical properties of each mixture studied, such as concentration, turbidity, the phase velocity and wave attenuation. That's why we brought in this work to consider two types of suspensions respectively, diluted and moderately diluted of clay. To understand the behavior of these mixtures, it is desirable to know their responses to ultrasonic waves.

2. Description of the experimental device

The experimental study was made in a parallelepiped container. To obtain usable signals, it is necessary to be not embarrassed by the reflections on the walls of the container. The recipient containing the mixture has a positioning system for mixtures and transducers. The container with distilled water only has a density about 999 kg/m^3 at 25°C, [3]. The speed of sound in distilled water is 1480 m/s, this value was measured at the temperature of 25°C, [4]. The figure 1 shows the ultrasonic immersion experimental setup using pulse transmission technique. The experiment used a pair of two transducers of 12mm diameter, unfocused broadband transducers (Panametrics,V303-SU,Waltham,MA). The transducers were mounted coaxially on a sample holder with the distilled water as sample of reference placed between the two transducers at near field distance from the transmitter. The ultrasound beam was perpendicular to the pore elongation of the container as shown in figure 1, and the whole setup was immersed in water at 25°C. The speed of sound in distilled water V_{DW} is temperature-dependent [5-6], (Eq.1).

$$V_{DW} = 1402{,}9 + 4{,}835\ T - 0{,}047016\ T^2 + 0{,}00012725\ T^3 \quad \text{(Eq1)}$$

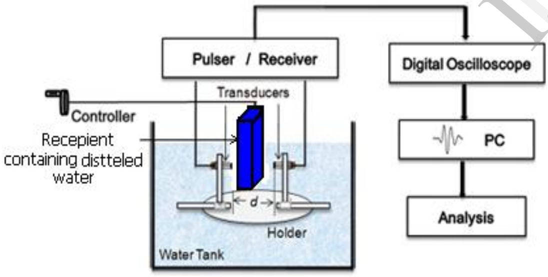
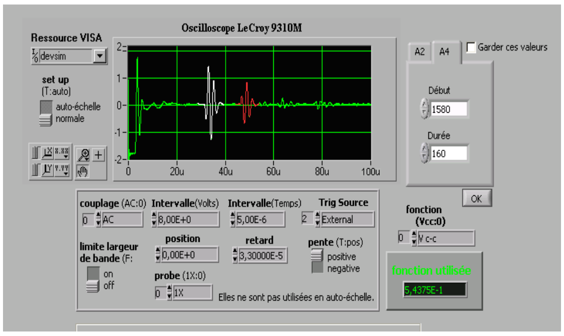


Fig.1: Schematic experimental device of the immersion experimental setup

The experimental device consists of a generator of pulses type Sofranel (5052pr) and two transducers. The generator sends a very short pulse on the piezoelectric transducer broadband. The generated pulse is sent directly to the Plexiglas container containing the suspension of clay with different concentrations. The received signals is amplified and digitalized by the oscilloscope type (HP54600B) and sent a means signals to a computer, by an acquisition of GPIB card (IEEE 488.2). The acquisition card is compatible with the LabVIEW graphical language. They are both manufactured by National Instruments, [7].

3. Ultrasonic measurement method

Figure 2 shows an example of plain experimental signal backscattered by the recipient containing the clay suspension. This signal is composed of two echoes A_2 and A_4 shown sequentially from left to right in figure 2. This signal is captured from the oscilloscope by the LabVIEW program. We found that the sample is characterized only by the echo A_2 (reflection at the interface between the second face of the first plate of Plexiglas and the mixture) and echo A_4 (reflection at the interface between the mixture clay and the first face of the second plate of Plexiglas).



Ressource VISA: devsim
set up (T:auto): auto-échelle / normale
☐ Garder ces valeurs
Début: 1580
Durée: 160
couplage (AC:0): 0 AC
Intervalle(Volts): 8,00E+0
Intervalle(Temps): 5,00E-6
Trig Source: 2 External
limite largeur de bande (F: on / off
position: 0,00E+0
retard: 3,30000E-5
pente (T:pos): positive / negative
probe (1X:0): 0 1X
Elles ne sont pas utilisées en auto-échelle.
fonction (Vcc:0): 0 V c-c
fonction utilisée: 5,4375E-1

Fig.2: Example of experimental signal backscattered by suspension

The procedure for the selection of two echoes A_2 and A_4 is made by the LabVIEW program. This program is designed in this work consists to separate each echo by a window time. However, the position of the two echoes remains unchanged against time and position of the raw signals. The user can manually select each echo in a different color from the other. Then the spectral amplitudes of the echoes A_2 and A_4 are determined by the application of the fast Fourier transform to the signal of figure 2. The amplitudes of the two spectra of echo are respectively A_2 and A_4 shown in figure 3.

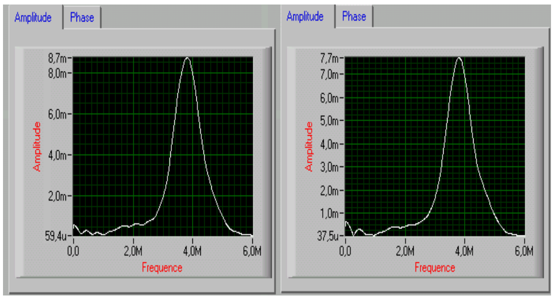


Fig.3: The spectral amplitudes of the echoes (A_2,A_4)

3.1. The phase velocity in clay suspension

The phase velocity for each mixture is given by the equation 2, [3]-[8]:

$$V_M(\upsilon) = \frac{\omega 2L}{\Phi_{Susp/Pg2} - \Phi_{Pg1/Susp}} \qquad \text{(Eq.2)}$$

Where : L is the thickness of the container

$\Phi_{Pg1/Susp}$ $\Phi_{Susp/Pg2}$ are the phases of the echoes (A_2; A_4)

The Fourier transform of the echo A_2 calculated by the program, provides the real part $R_2(\omega)$ and the imaginary part $I_2(\omega)$, which allows to calculate the phase, (Eq.3):

$$\Phi_{Pg1/Susp} = \mathrm{arctg}\left[\frac{I_2(\omega)}{R_2(\omega)}\right] \qquad \text{(Eq.3)}$$

While the Fourier transform of the echo calculated by the program A_4, yields the real component $R_4(\omega)$ and the imaginary part $I_4(\omega)$, which calculates the phase (Eq.4) :

$$\Phi_{Susp/Pg2} = \mathrm{arctg}\left[\frac{I_4(\omega)}{R_4(\omega)}\right] \qquad \text{(Eq.4)}$$

In the calculation of the two expressions of the equations (Eq.3) and (Eq.4), two spectra whose phases varies between $-\pi/2$ and $\pi/2$ is obtained. We developed an interface in the LabVIEW graphical software with an algorithm able to place the phases in continuous form. Using the algorithm of the phases and LabVIEW interface, we determined the speed of sound in the enclosed mixture as function of time and frequency.

3.2. The attenuation of ultrasonic waves in clay suspension

The ultrasonic attenuation in each clay slurry is given by the equation 5: [3]; [8-9-10].

$$\alpha(\alpha) = -\frac{1}{2L}\ln\left[\left(\frac{A_4}{A_2}\right)\xi_{\text{réf}}\right] \qquad \text{(Eq.5)}$$

Avec $\xi_{réf} = \dfrac{(Z_{Pg} + Z_{Susp})^2}{4\,Z_{Pg}\,Z_{Susp}}$

$Z_{Pg} = \rho_{Pg}\,C_{Pg}$

and $Z_{Susp} = \rho_{Susp}\,C_{Susp}$

Where Z_{Pg} is the acoustics impedance in Plexiglas, and Z_{Susp} is the acoustics impedance in suspension.

4. Preparation of clay suspensions

The dry clay preventing from the dam is sieved using a sieve type (60 mm mesh Stainless Nylon, 1 to 20 microns), which eliminates the sand, blood clots and large particles. The clay suspensions were prepared from different amounts of dry clay from dam and distilled water. Then, they are enclosed in a container immersed in a thermostated half tank set at a temperature of 20°C. The container consists of two sheets of Plexiglass. The geometry of the problem is shown schematically in figure 4. Transducers center frequency 5MHz and 10MHz type (PANAMETRICS-V358-SU/V35) were successively used for these experiments.

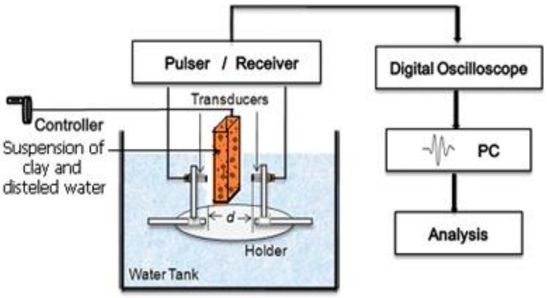


Fig. 4: Experimental device

To prepare the clay suspensions studied, taking into account the physical and chemical properties of the suspension, [11].

We have included in the preparation of each mixture, the calculation of:

- The density of the mixture (ρ_m),
- mass fraction (C_m) or the volume fraction (C_v),
- the average size of clay particles <a>,
- density of clay grains (ρ_c).

The mass of the mixture of each clay slurry (M_m) is equal to the mass of distilled water (M_f) plus the mass of clay particles (M_c). Where: $M_m = M_f + M_c$

The volume of each clay suspension (V_m) is equal to the volume of fluid (V_f) over the particle volume (V_c).

Where: $V_m = V_f + V_c$

The mixture is defined as the set of physical mechanisms to homogenize the various compounds present in the fluid. When the type of fluid is considered like a solution, we use the concept of concentration to characterize the relative proportions of solute and solvent. In the case of suspension, the concept of total concentration or the concept of volume fraction of clay grains are preferred. In general, we use the term of the concentration. The mass fraction of clay grains is determined by the ratio, (Eq.6):

$$C_m = \frac{M_c}{(M_c + M_f)} = \frac{\rho_c(\rho_m - \rho_f)}{\rho_m(\rho_c - \rho_f)} \qquad \text{(Eq.6)}$$

Where ρ_f is the density of the fluid.

5. Results and discussions

The following study is performed using the transmission method, which consists in using of two transducers aligned opposite to each other. We send the pulse directly into the suspension and the other transducer receives ultrasonic waves that have passed through the mixture. Each measure the phase velocity and attenuation is repeated 10 times, to minimize errors, then we take the average values and the curve of the speed and the attenuation depending on the sedimentation time is plotted. After sufficient agitation which ensures the average distribution of the clay particles by volume element, a pulse is sent directly to the container containing the mixture and the suspension is left settled.

5.1. Attenuation measurement of waves in clay suspensions

5.1.a. Measuring attenuation at 5MHz. The attenuation measurements were made for theses concentrations (5g/l, 10g/l, 20g/l, 30g/l and 40g/l) of clay grains in distilled water with a transducer center frequency of 5MHz contact. These concentrations vary between the minimum value and the maximum value of the ratio of clay in dam water, (Fig. 5).

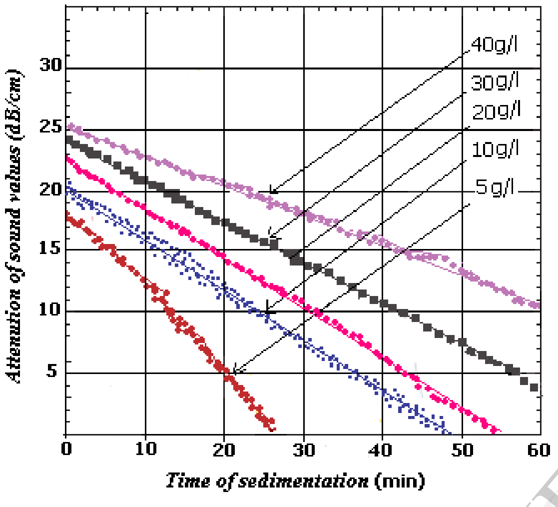


Fig. 5: Attenuation curve versus time settling of clay suspension with different concentrations

From the analysis of the figure, we see that when you have a higher quantity of clay in suspension, the attenuation is more important and when the suspension have a very low concentrations of clay, there is a significant fall of the attenuation coefficient and the slope of each curve decreases. We can explain this phenomenon by the fact that the forces and interactions between clay particles become more important, because the suspension becomes very concentrated on clay grain and it has trouble to settle very quickly.

5.1.b. Attenuation measurement at 10 MHz. Under the same operating conditions mentioned above in the study by the 5MHz transducer. We start recording the attenuation versus time of settling, after 25 minutes of exposure of the vessel containing the clay mixtures to ultrasonic waves generated by the transducer 10MHz. The curves in figure 6 represent the attenuation as a function of sedimentation time for each clay concentration. This figure shows that each suspension is characterized by an acoustic signature. In this case, we can see that the values of attenuation decreases and the fall of the attenuation increases as the concentration decreases. It can be explained by the fact that when we increased the frequency of the transducer 5 to 10MHz, the regime of forced sedimentation is established. In other words, the ultrasonic waves have counterbalanced the equilibrium of forces in each mixture promoting gravitational forces despite other forces of Van der Waals and sterical forces, causing a fast sedimentation of clay grains.

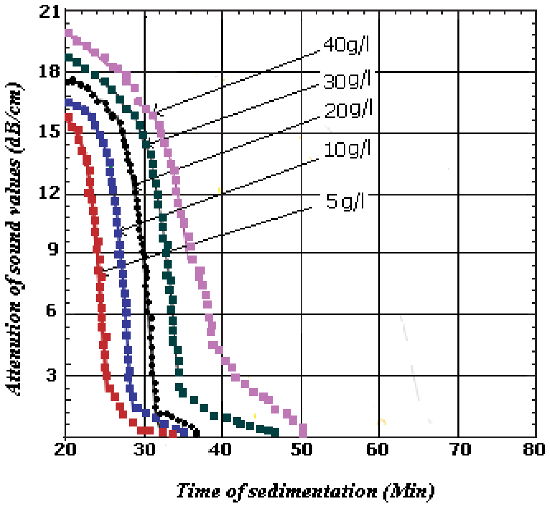


Fig. 6: Attenuation curve versus time settling of clay suspension with different concentrations

5.2. Measurements of waves velocity in clay suspensions

5.2.a. Measures at 5MHz. The measurements of the velocity were made for the clay concentrations (5g/l, 10g/l, 20g/l, 30g/l and 40g/l) with a transducer of central frequency is 5MHz. the figure 7 shows the monitoring of ultrasonic velocity versus sedimentation time concentrations for each concentration. This figure shows that the values of the velocities are almost constant throughout the experiment for each concentration. We also note that each concentration is characterized by a given speed and when we increase the quantity of clay in distilled water the velocity increases, (Fig. 7).

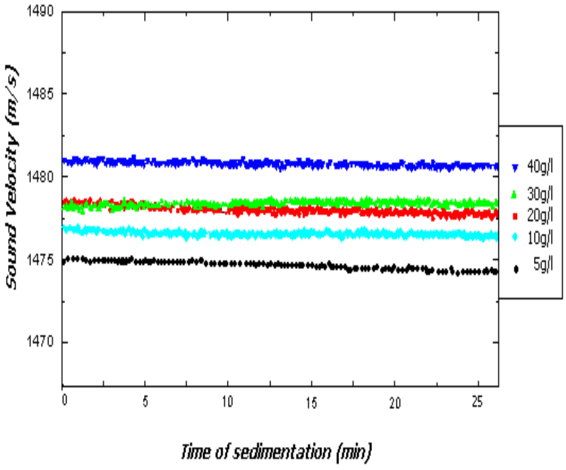


Fig.7: Curves sound velocity versus the sedimentation time, for different concentrations

5.2.b. Measures at 10MHz. Under the same operating conditions previously followed in the study by 5MHz transducer and after 25 minutes of exposure of the vessel containing the clay mixtures to ultrasonic waves generated by the transducer 10MHz. We start recording the velocity versus time of settling. Figure 8 shows the monitoring of velocity versus sedimentation time for the concentrations (5g/l, 10g/l, 20g/l, 30g/l and 40g/l), with a transducer of 10MHz. This figure shows that the values of the velocities are almost constant throughout the process for each mixture of clay. We also note that each concentration is characterized by a given speed and the values of the velocity were reduced in comparison with the values obtained with the transducer of 5MHz. We also note that each mixture acquires an acoustic signature.

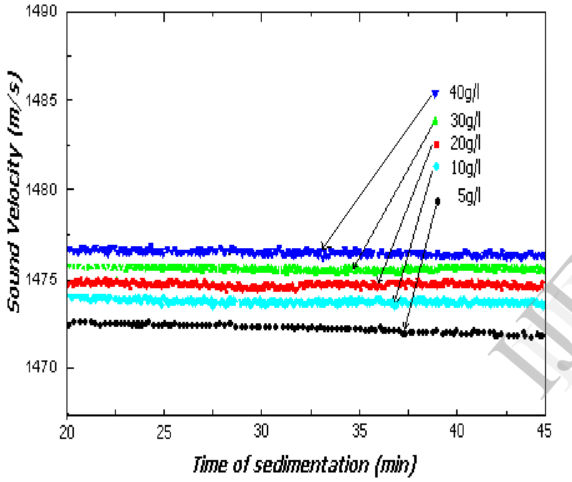


Fig.8: Curves of sound velocity versus settling time, for different concentrations

Table 1 gives the values of the ultrasonic velocity for different clay concentrations studied with two transducers of 5MHz and 10MHz. We can conclude that when we increase the frequency of the transducer the values of the phase velocity has decreased. We may therefore conclude in the same way as attenuation that when we increase the frequency of the transducer, the regime of forced sedimentation is established while causing rapid sedimentation of clay particles. The curves of attenuation and velocity plotted were averaged, in other words that the experiments are repeated ten times for each measurement to minimize errors.

Tab. 1: Velocity for different concentrations of clay

Concentration (g/ l)	Values of velocity (m/s)	
	5MHz	10MHz
5	1475	1472,5
10	1477	1474
20	1478	1475
30	1479	1472
40	1481	1477

6. Conclusion

We have presented experimental results that allow monitoring two main parameters, velocity and attenuation of sound waves. These two parameters which will characterize the treatment process following water from dam. We noted that each concentration has a specific value of attenuation and velocity phase. We found after the first measures in this work that with increasing concentration of clay grains in a suspension the attenuation and velocity increases too, whatever the nature of the transducer, and each clay mixture has an acoustic signature. It can be concluded, that we can easily to know the quantity of clay in each mixture by measuring the phase velocity and/or attenuation. We also showed that with increasing the frequency of transducer there are a significantly increases in the sedimentation speed of clay grains, but this only in the case of dilute and moderately diluted suspensions. In the case of concentrated clay suspensions, the experimental approaches in laboratories are extremely rare and diverse in the literature, so you have to use other acoustic theoretical approaches, such as the model of Waterman and Truell, [12-13] which allows to the calculation of the phase velocity and ultrasonic attenuation coefficient of coherent wave in such suspensions. We can therefore conclude that the process monitoring of sedimentation is performed with a large precession by measuring the attenuation and/or ultrasonic velocity. The results show the fundamental role played by the systems of ultrasonic waves to characterize and investigate the dilute and moderately diluted of clay suspensions.

10. References

[1] N. Marleni, S. Gray ,A.Sharma,S. Burn,N. Muttil."Impact of water source management practices in residential areas on sewer networks".Water Sci Technol. (2012); 65(4):624-42.

[2] Larrarte F, François P. Attenuation of an ultrasonic beam by suspended particles and range of acoustic flow meters in sewer networks. Water Sci Technol. (2012); 65(3):478-83.

[3] B. Faiz, "Contrôle ultrasonore de la prise en masse d'un yaourt et d'une résine époxy", Thèse de Doctorat d'Etat, Agadir, Maroc, (1997).

[4] W. D. Wilson, Velocity of Sound in Distilled Water ; J. Acoust. Soc. Am. Volume 30, Issue 7, pp. 684-684 (1958).

[5] KA Wear, “Frequency dependence of ultrasonic backscatter from human trabecular bone: Theory and experiment”; The Journal of the Acoustical Society of America, (1999).

[6] KA Wear, BS Garra, “Assessment of bone density using ultrasonic backscatter”; Ultrasound in medicine & biology, (1998) – Elsevier.

[7] National Instrument, "Initiation à LabVIEW", Édition de Février (2001).

[8] D.J. McClements, P. Fairley, “Ultrasonic Pulse Echo Reflectometer”, Ultrasonics, 29, 58–60, (1991).

[9] D. K. Mak, "Comparison of various methods for the measurement of reflection coefficient and ultrasonic attenuation", British Journal of NDT, (1991); 33(9), pp. 441-448.

[10] A.Hamine, B.Faiz, D.Izbaim, A.Moudden. Ultrasonic Technique for the Quality Control of Water Containing Clay. Journal of the Acoustical Society of America, (2008), volume 123, no 5, p. 3233.

[11] A. Hamine, B. Faiz, A. Moudden, A. Menou, A. Benallou, D. Izbaim, G. Maze, D. Décultot, “Ultrasonic Attenuation Measurement Method for Characterization of Clay Particles Mass Fraction in Dilute Suspension”; Journal High Temperature Materials and Processes. Volume 28, Issue 6, Pages 369–378, March (2011).

[12] PC Waterman, R Truell, “Multiple scattering of waves”; Journal of Mathematical Physics, (1961).

[13] DJ McClements, “Ultrasonic characterisation of emulsions and suspensions”; Advances in Colloid and Interface Science, Elsevier (1991).