19th INTERNATIONAL CONGRESS ON ACOUSTICS
MADRID, 2-7 SEPTEMBER 2007

TIME REVERSAL DETERMINATION OF PARTICLE CONCENTRATION IN LIQUID MEDIA

PACS: 43.35.–c
Pérez, Nicolás[1]; Negreira, Carlos[1], Canetti, Rafael[2]
[1]Instituto de Física, Facultad de Ciencias, Universidad de la República; Igua 4225; Montevideo Uruguay. nico@fisica.edu.uy, carlosn@fisica.edu.uy
[2]Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República; J. Herrera y Reissig 565; Montevideo Uruguay. canetti@fing.edu.uy,

ABSTRACT

The determination of particle concentration in liquids has important applications in the industry. In the last years, environmental applications increased the importance of the determination of concentrations in real time. This implies the necessity of robust and low cost techniques.
In this work we show the application of the Time Reversal technique to determine the particle concentration level in liquid media. The signal obtained in the Time Reversal process has an acoustic signature of the media by which the waves propagate. This signature is sensible to global changes of media properties, like temperature or the statistical distribution of diffusers.
As specific application example make we show the determination of bacteria concentration in a biological reactor for the treatment of remainders of the milky industry and the determination of the evolution in time of the mud level.

ACOUSIC TIME REVERSAL

Time reversal techniques of acoustic waves have produced several applications. On the one hand, and maybe unexpectedly, they have contributed to the study and better understanding of Physics basic phenomena [1], and on the other hand, they have given way to the focusing of acoustic waves in unfavorable conditions such as heterogeneous media, or media with multiple scattering [2]. It is possible to increase the quality of ultrasonic images, the characterization of materials, and it allows for an improvement in communication systems such as the sonars [3]. We can also mention clever applications of generation of ultrasonic power that have a great potential for medical therapy [4]. Currently, they are proposing the use of this technique to generate 3D imagery [5].
Time reversal process starts with the system characterization, for this we emit a thin pulse, like a Dirac's delta and obtain the impulse response h(r,t). After that this signal is inverted in time h(r,T-t). and reemitted. Here *T* is the delay in the reemission process and *r* is the spatial point for the signal reception. We assume a fixed source and a variable reception point *r*.[6] [7]
Finally the signal is received in the same spatial point r and we obtain the convolution product

$$y(r,t) = h(r,T-t) \otimes h(r,t) = \int_{-\infty}^{\infty} h(r,t)\cdot h(r,t-T+t)dt$$

Is easy to see that signal is the autocorrelation of h de la forma

$$y(r,t') = \int_{-\infty}^{\infty} h(r,t)\cdot h(r,t'+t)dt \qquad t-T=t'$$

In the frequency domain this product is

$$Y(r,w) = \Im\left(h(r,T-t)\otimes h(r,t)\right) = H(r,w)\cdot H^{*}(r,w)\exp(jwT)$$

The effect of the product H.H* is to eliminate all face difference for each frequency given a maximum in the initial time.
In the practice we work with a discrete set of N frequencies. This can be write

$$Y(r,w) = \sum_{-N}^{+N} A_n^2 \exp(jw_n t)$$

For this equation we can see what Time Reversal maximum is proportional to signal energy.

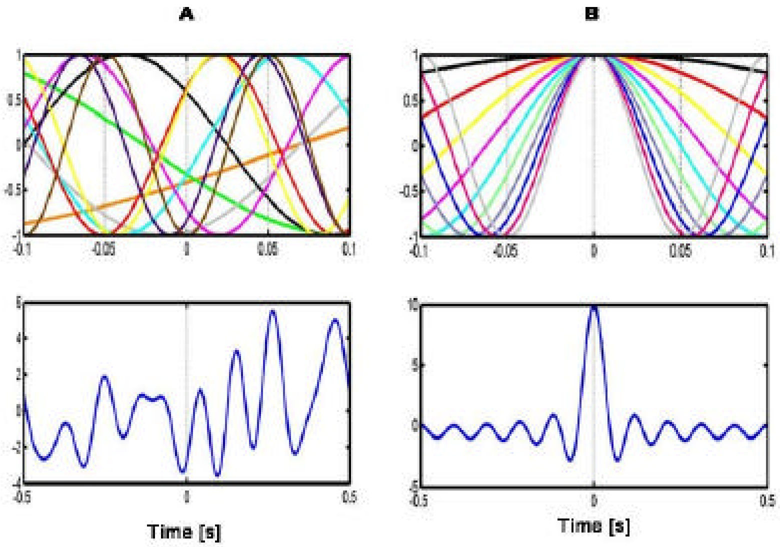

Figure 1.- A Signals add out of face. B signals added in face.

Time Reversal sensibility to global properties.

When an acoustic wave propagates in a media, a part of total energy is loosed. This produces an amplitude diminution of the focus. Nevertheless the focalization occurs in attenuate media due to the speed of the wave is the same in both senses, when the wave starts at the source and when come back.

The Time Reversal focus is not sensible to local changes in the media, like a small scatter, but depends on global properties like statistic distribution of diffusers or other energy loss factor. In this way we can use the amplitude of Time Reversal focus to measure the particle concentration.

Signal symmetry and spectral identification.

A criterion to determinate de quality of Time Reversal process is the symmetry of the signal around the focus. When an external factor causes a change in the media that affects one frequency component, the symmetry is broken. Next figure shows this effect. This is another property that can be used to measure the particle concentration. If the scatters in the media causes a difference between the signals en the first emission and the reemission inverted in time, this difference is located in a thin frequency band. This frequency is found looking at the loss of symmetry in the focus.[8]

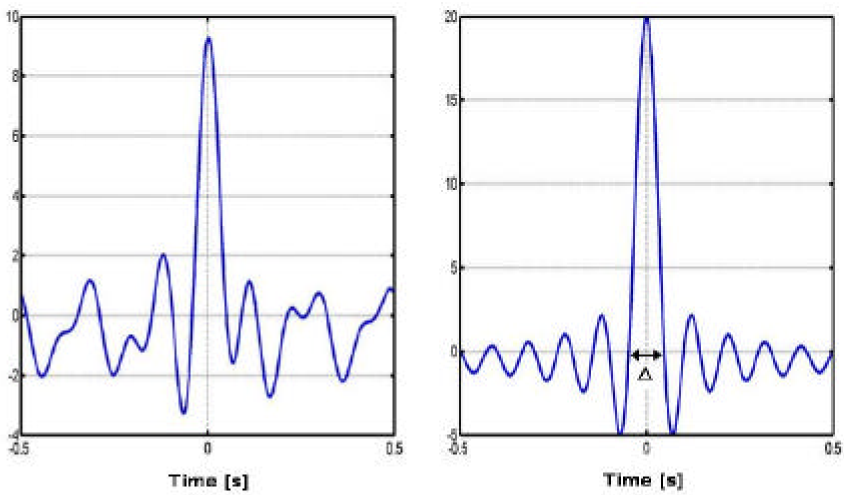

Figure 2.- Symmetry loos. In the left we show a signal with symmetry loss due a face error in one frequency component. In right the same signals in face, with Δ depends on the high frequency in the signal spectrum.

APLICATION: Ultrasound Measurement of Organic Product Precipitation in Biological Reactors

Problem statement

In the biological reactor under study at least two types of bacteria are had with the purpose of degrading organic remainders. This application is made in two reactors developed for research in the Chemical Institute (Facultad de Ingeniería - UdelaR).[9] [10]

Figure 3.-Laboratory biologic reactors

These anaerobic reactors are developed to study biologic wastewater treatment for the dairy industry.

Both bacteria and the remainders have a slightly superior density to water, this causes that when the reactor not be shaken the particles precipitate.

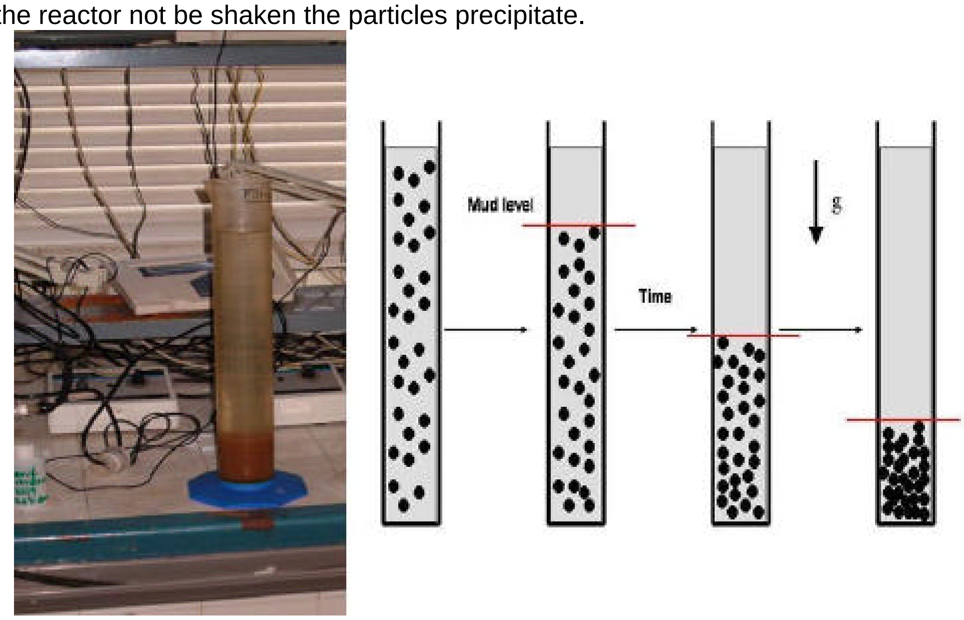

Figure x+1.- Time evolution of solid in a sample.

When the time forwards we observe two regions divided by a fuzzy line, in the upper we observe dirty water and in the lower a suspension of particles.

The division is called mud level; it can be distinguished at first and is like a cloud.

Objectives of the work

The main objective of this work is to probe ultrasonic techniques can determine process parameters and give information about the state of the reactor. For it two types of measurement are proposed:

- Speed of sound vs. concentration, we tray to determine a relation between the speed of sound in the media and the bacteria concentration. For it we Time Reversal technique.
- Evolution in time of the mud level, determine the mud level using the ultrasonic echo and compare it with the visual observation. In this case traditional time of fly technique was used.

Time Reversal measurement of particle concentration.

This measure is made in a special cavity exterior to the reactor. The Time Reversal maximum is measured and the dependence with the concentration is study.
The cavity used for this experience has a parallelism adjust and a continuous temperature sensing to compensate the measure.

The sampling preparation is made using the follow procedure:
First we take a sample of the reactor content and wait for the precipitation of the mud; we obtain the background water without bacteria.
Second we take a one litter sample of the reactor, this is the 100 % sample.
Third 100 cc of the sample is discarded and the rest is mixed whit the background water, this made the 90 % sample.
The process is repeated for 80 %, 70 %, … , 10 %.

As we show in previous section the maximum of the focus in Time Reversal process is proportional to signal energy, for this amplitude is measured in Joule.
Next picture shows the maximum of the focus vs. concentration. In this we can see the diminution of the amplitude when the bacteria concentration is increased. This is easy of understand because the energy of the signal y loosed in the scattering process when the acoustic wave interacts with the bacteria.

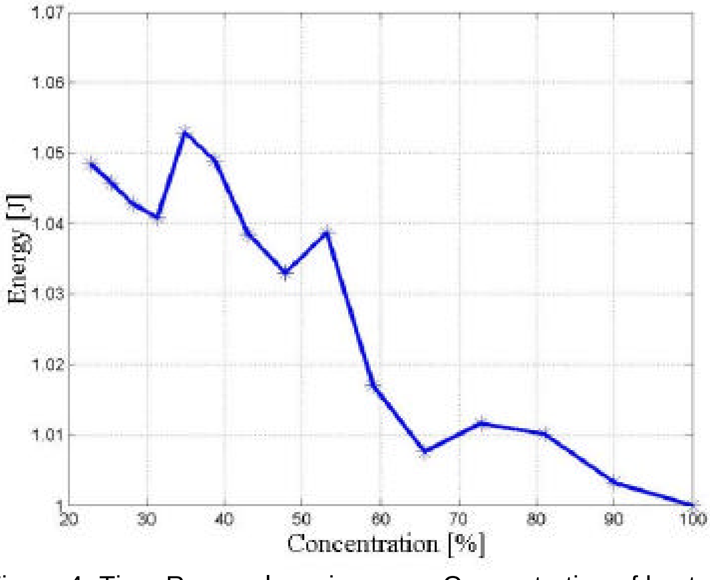

Figure 4.-Time Reversal maximum vs. Concentration of bacteria.

Evolution in time of the mud level

In the next figure we show the set up to measure the evolution in time of the mud level, a piezoelectric transducer is placed in the upper reactor surface working in pulse-echo mode.

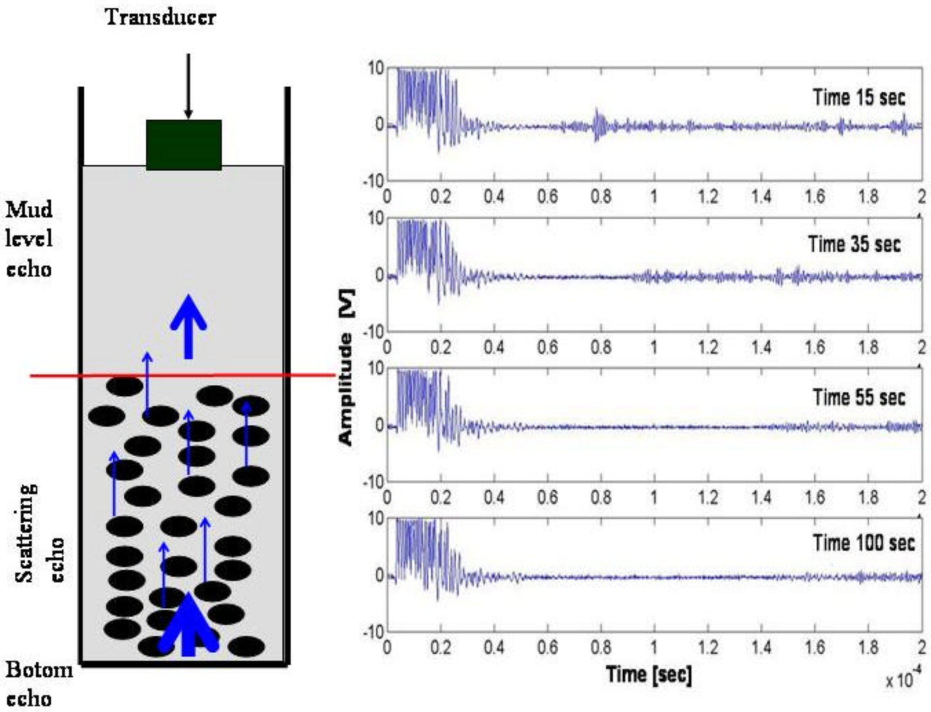

Figure 5.-Sinals received form mud level at different times.

In this mode the transducer emits a short pulse and receives the echo produced by the media under study. We use commercial ultrasonic equipment, and the digitalized data are collected in a PC for analysis. At same time a visual measure is performed.
This experiment is made in two hours, and the result is sowed in next figure.

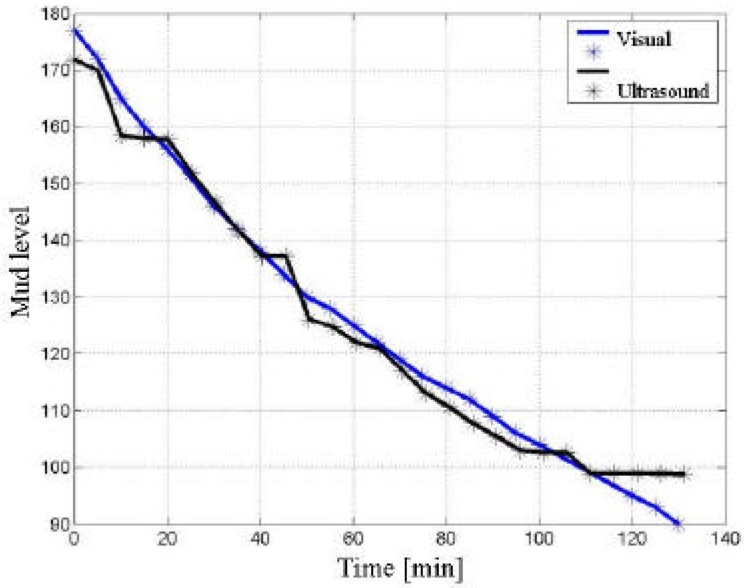

Figure 6.-Mud level evolution, in blue visual evolution and in black ultrasonic measure.

CONCLUSIONS AND FURTHER WORK

Time Reversal maximum is a rough method to estimate the bacteria concentration for this application. We also measure the time of fly in a pulse echo mode, this measure is sensible to the particle concentration but is very dependent on the sample temperature. This is a great difficult to make the measure in a real reactor a not in a laboratory.
At this moment we are making a new set of samples using Time Reversal symmetry, this is the further work and we hoped to have the results to show in ICA2007.
The pulse-echo technique used for mud level evolution give a good result.
Both measures complement a physic-chemical model to predict de evolution of the bacteria population in the reactor.

References:

[1] P. Roux, J. De Rosny, M. Tanter, M. Fink : The Aharonov-Bohm effect revisited by an acoustic time-reversal mirror Phys. Rev. Lett. 79 (17), pp 3170-3173, 1997.
[2] M. Fink, J. De Rosny : Time reversal experiments in random media and in chaotic cavities. Nonlinearity vol. No.15 (1) , pp 1-18, 2002.
[3] J. Bercoff, M. Tanter, M. Fink : Sonic boom in soft materials : the elastic Cerenkov effect. Appl. Phys. Lett. 84 (12), pp 2202-2204, 2004
[4] A. Derode, P. Roux, M. Fink : Acoustic time-reversal through high-order multiple scattering. Phys. Rev. Lett.75 (23), pp 4206-4209, 1995.
[5] C. Prada, S. Manneville, D. Spoliansky, M.Fink : Decomposition of the Time Reversal Operator: Application to detection and selective focusing on two scatterers. J. Acoust. Soc. Am. 99 (4), pp 2067-2076, 1996.
[6] M. Fink. “Time reversal of ultrasonic fields - Part I: basic principles”. IEEE Trans. Ultrason., Ferroelec., Freq. Contr. 39 (5), pp 555-566, 1992.
[7] M. Fink. “Time-reversed acoustic”. Scientific American 1999. pp 91-97.
[8] N. Pérez: Inversión Temporal de Ondas Ultrasónicas en Cavidades Acústicas. Tesis doctoral, Universidad de la Repúbica-Uruguay.
[9] S. Gutiérrez and M. Viñas: Anaerobic degradation kinetics of a cholesteryl ester.Water Science and Technology Vol 48 No 6 pp 141–147 © IWA Publishing 2000
[10] S. Gutiérrez, A. Ferrari, A. Benítez, S. Hermida, R. M. Canetti: Carbon and nitrogen removal from dairy watewatering a laboratory sequential batch reactor system. 2nd Mercosur Congress on Chemical Engineering