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GAS RATE MEASUREMENTS IN A TWO-PHASE FLOW BY ACOUSTIC MEANS

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Authors present an ultrasonic method for measuring the rate of dissolved gas in a liquid. The aim of this analyse is to control the gas rate in a low temperature and high pressure flow of liquid hydrogen or liquid oxygen. The interest is to prevent the defective behaviour of carburant loading pumps in rocket engine.

A preliminary study is realised on a water column, without average flow, to the basis of which are generated bubbles of air. The ultrasonic method used to detect the gaseous phase appearance consists in recording the amplitude of waves transmitted through the two-phase flow. A technical is proposed to measure average and local gas rate. Acoustic tests have been realised on two types of columns (glass tube with square section and polymetacrylate tube of round section). In each configuration and for several measuring frequencies (134 to 600 kHz), results show a quasi-linear decreasing of the amplitude (in logarithmic coordinate) as the air gas rate increases (0 to 9%).

1. Introduction

It is known that the presence of gas bubbles in a liquid disturbs the acoustic wave propagation. The acoustics impedance of the liquid and the gas are very different, even if the numbers of bubbles is small. Their presence can allocate considerably the acoustic propagation. The bubble can be considered as an acoustic resonator and can therefore enter in resonance when it is submitted to a resonant field. The resonance frequency is inversely proportional to the bubble diameter, so during the resonance, amplitude are more important, and a considerable energy is taken from the incident field which is omnidirectionnally scattered. Generally, gas bubbles influence the absorption, the reverberation, the sound propagation in the medium and consequently the transmission or the reflection of the incident wave.

Many theoretical and experimental studies deal with the "direct problem" of the alteration of the acoustic propagation by bubbles [synthesis document of M.A Gilles]. For example, the literature report the alteration of sonar performances by gas bubbles dissolved in the sea water (back-scattering layers).

The "inverse problem" is also important, it consists in detecting the presence of bubbles from the perturbation of an acoustic wave. Applications are various as :

- locating of the boats wake by cavitation generated bubbles or the wake due to propellers ;
- detection of air bubbles in the blood of skin divers after a too rapid decompression ;
- industrial device supervision such that thermal exchangers where the appearance of the nucleation phase reduces the efficiency, etc.

This study is typically an "inverse problem". Indeed, from the analyze of the propagation of an acoustic wave in the liquid, we have evaluated the dissolved gas rate in this fluid. The final objective of our work is to control the gas rate in a low flow temperature and high pressure liquid (hydrogen or oxygen) for detecting the defective behavior of fuel loading pumps in rocket engine.

2. Determination of influential parameters and choice of the technique

The bubbles resonance frequency of radius superior to 100µm is given by the next simplified relationship :

$$f_o = \frac{1}{2\pi R_o}\left[\frac{3\gamma P_o}{\rho}\right]^{1/2} \qquad (1)$$

Where: R_o : radius bubble

P_o : static pressure in the liquid

ρ : volumic mass in the liquid

$\gamma = \frac{C_p}{C_v}$ gàs specific heat report

Generally, the resonance frequency is inversely proportional to the bubble radius. In the case of air bubbles at atmospheric pressure (γ=1.4), the relationship (1) can be written :

$$f_o = \frac{3.26}{R_o} \qquad (2)$$

The diffused and absorbed energy by the air bubble depend of the air bubble efficient section which in a several case does not correspond to its geometrical section.

This efficient section defined by the ratio between the diffused energy (scattered) and absorbed over incident energy, is given by :

$$\sigma_t = \frac{4\pi R_o^2\left(\frac{\delta}{kR_o}\right)}{\left(\frac{f_o^2}{f^2}-1\right)^2+\delta^2} \qquad (3)$$

Where : $k = \frac{\omega}{C} = \frac{2\pi f}{C}$; wave number in the liquid

C ; celerity ;

$\delta = \delta_{ray.} + \delta_{vis.} + \delta t_{th.}$; damping term equal to the sum of radiated, viscous and thermal damping.

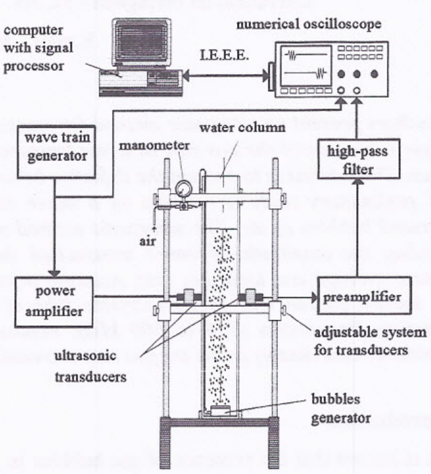
The bubble efficient section is proportional to the bubble radius, so the absorbed and diffused energies increase with the bubble radius. In a bubbles spray of different size, the acoustic wave attenuation is principally affected by a few large bubbles. There will be therefore a shift of the resonance frequency for the low frequencies.

In liquid, the measure of the gas rate is realized by using several techniques : Doppler effect [R.Y. Nishi - P. Palisson et al.], acoustic emission [T.G. Leighton et al.] and acoustic transmission [E.L. Carstensen, L.L. Foldy - P. Arzelies and O. Gérard - C. Journeau - H.J.M. Hulshof et al. - F.W. Gibson]. There results show that the frequency, celerity and attenuation transmitted wave are the parameters the most important in this process.

3. Experimental set-up

The ultrasonic method used to detect the apparition of the gaseous phase consists in recording the amplitude evolution of a waves train transmitted through the diphasic medium. We applied this method to a water column of 60cm high, without average flow speed, at the basis of which are generated air bubbles (fig. 1).

Fig. 1 : Experimental set-up



The air bubbles are obtained by compressed generator which supply air through a porous stone disposed at the bottom of the water column. The air rate is variable and depends of the air pressure (pressure ranging between 0 and 5 bars controlled by a manometer). This experimental device is completed by two ultrasonic transducers placed on each side at 40cm above the basis of the column. The acoustic coupling between transducers and tube is assumed by a gel (coupling gel D-Sofranel) often used in no destructive control.

The electronic instrumentation is composed by :

- *for emission* : a wave train generator with variable frequency (width of the waves train : 20 to 50µs, recurrence : 20ms) followed by a power amplifier from 50 to 500W ;

- *for reception* : a wide-band preamplifier (0 to 60dB) and a high pass filter (adjustable Fc 0 to 2MHz) ;
- a numerical oscilloscope HP-100MHz equipped with an I.E.E.E. interface that visualizes, memorizes and then transfers analogical signals to a microcomputer which assumes the process (stockage, F.F.T. ...).

4. Results and interpretations

The air pressure variation increases the quantity of injected air in the liquid and consequently the air rate. The bubbles size increase when they are near the surface, so the volume gas rate is not constant along the column water. A good estimation of the average air rate is obtained by measuring difference between the level in the column without and with injected air. It is interesting to know the local or real rate at the level of the transducers.

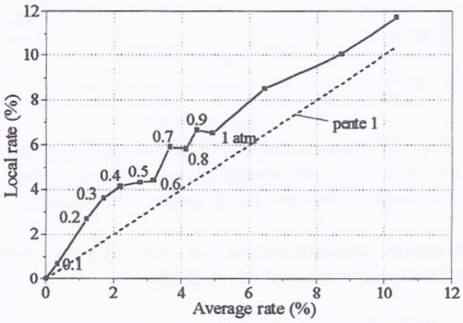


Fig. 2 - Local air rate (to the level of transducers) vs. the average air rate.

So, we undertake measure on a sample of the diphasic medium with a "bubbles trap" (methyl polymetacrylate -M.P.M.- cylinder 61x53mm closed to its extremities by two revolving discs). The local air rate is obtained by weighing difference (bubbles trap filled with water or with the sample water-bubbles). These results are presented versus the average air rate on the figure 2. The difference can be explained by the fact that the bubbles size is not the same along the water column. For the continuation of tests, we will take the average rate into account, which is more stable and less disturbed by turbulence phenomena and recirculation. The ascension of bubbles disturbs the transmitted wave which amplitude is strongly modulated. So as to avoid this phenomenon, we proceed to an average of the 256 acquisitions which duration is approximately equal to 2 minutes.

Acoustic measurements on the squared section glass column (150x150mm), thickness 10mm.

The frequencies spectrum of the ultrasonic transducers (fig. 3) coupled to the experimental device presents resonance peaks (F=136, 150, 300, 510 and 600kHz) corresponding to the resonance frequency of the piezoelectric element and materials intervening in the setting. For these frequencies, the energetic efficiency and the amplitude of the transmitted wave present a maximum.

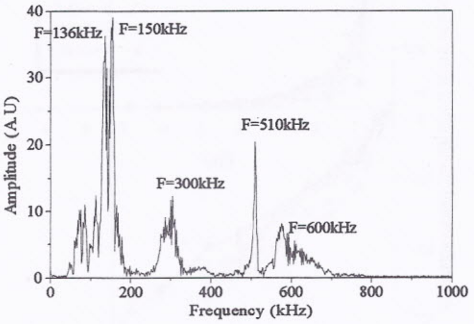


Fig. 3 - Frequencies spectrum of the totality transducers-glass water filled tube.

For these frequencies, we have recorded the evolution of the transmitted wave amplitude versus the average air rate in the liquid. An analogical recording example of emission and reception signals for several air rates is presented on the figure 4.

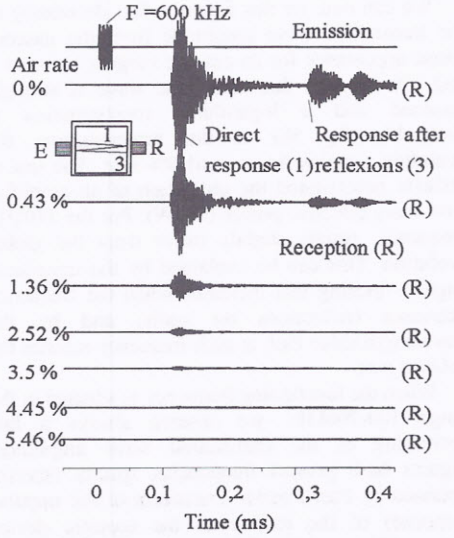


Fig. 4 – Acoustical responses obtained to F=600kHz for different average air rate.

These results presented by dimensionless parameters are presented on the figure 5a and are comparable to these obtained by F. W. Gibson.

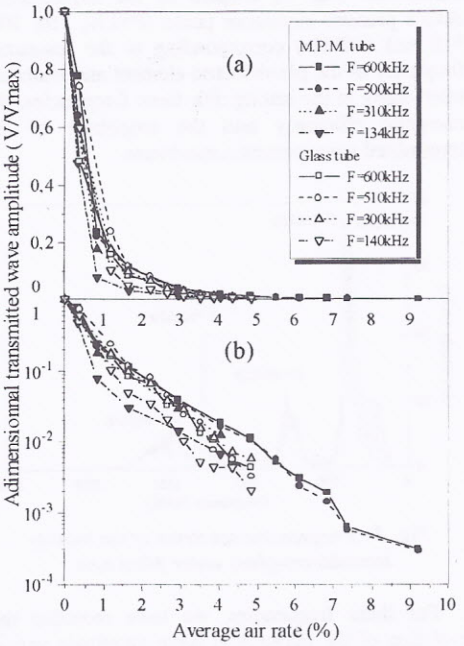


Fig. 5 - Transmitted wave amplitude vs. average air rate for several functioning frequencies (square tube glass-circular M.P.M. tube).

We can note on this figure, a fast decreasing of the transmitted wave amplitude from the gaseous phase appearance for an air rate ranging between 0 and 1%. Beyond this value, the wave is strongly lessened and a logarithmic representation is preferable (fig. 5b). In this representation, the evolution remains linear until 9% rate. The test at 600kHz necessitated the utilization of an amplifier with more effective power (500W). For the 140kHz frequency, results slightly differ from the global evolution. This can be explained by the transducer angular opening that increases when the frequency decreases (reflections on walls) and by the wavelength value that, at such frequency reaches the bubbles size.

When the functioning frequency is situated in the range 100-700kHz, we observe always a fast decreasing of the transmitted wave amplitude. Figures 6a-b present frequencies spectra (spectra obtained by Fast Fourier Transform of the impulse response) of the totality of the acoustic device obtained for several average air rates.

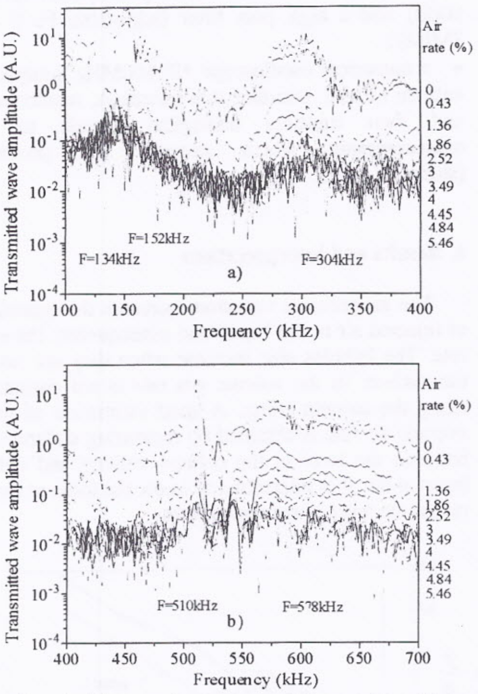


Fig. 6 - Frequencies spectra of the totality of the acoustic device for several average air rate values. a) range : 100-400kHz. b) range : 400-700kHz.

Acoustic measurements on the M.P.M. tube 140mm diameter and 5mm thickness.

With the same experimental device, we have realized identical acoustic measurements on a water column inside a cylindrical M.P.M. tube.

In this new configuration, transducers are coupled to the tube by "cups" on cylindrical surface (thickness=10mm) which slightly modifies the frequencies responses (fig. 7) that present more displayed peaks.

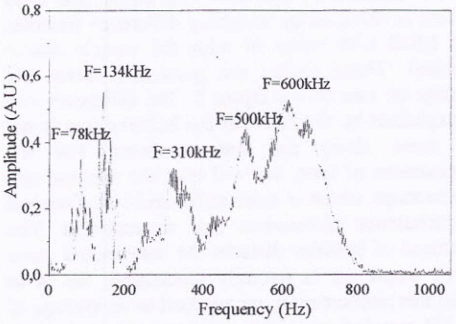


Fig. 7 - Frequencies spectrum of the totality transducers- M.P.M. water filled tube.

An example obtained by an analogical recording for F=600kHz is presented on the figure 8 and shows the presence of the direct and the reflective echo after three crossings between transducers.

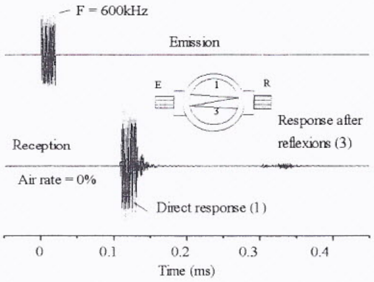


Fig. 8 - analogical signal recording obtained to F=600kHz without bubbles presence (cylindrical M.P.M. tube).

Results reported on figures 5a-b present an identical evolution to these obtained with the glass column squared section and show a quasi-linear evolution (in logarithmic scale) until 9% air rate. One notices, as previously, and for the same reasons, a different slope for the low frequencies (F=134kHz).

5. Conclusion

After analyzing some ultrasonic techniques (Doppler effect, acoustic emission, reflection and acoustic transmission), we choused the most appropriate method and acoustic parameters to solve our problem. In our case, the measurement of the gas rate in a hydrogen or oxygen liquid flow, the amplitude measurement of a transmitted ultrasonic wave seems better adapted.

This feasibility study was completed by an experimentation device for the gas rate determination in a water column. Acoustic measurements of a transmitted waves train through the diphasic medium water-air bubbles show an exponential decrease of the direct wave amplitude versus average air rate in the liquid (until approximately 9% rate). This evolution depends of the frequency. For explored frequencies (300 to 600kHz), acoustic measurements give identical results. To lower frequencies (130-140kHz), parasitic reflections on the tube walls modify the amplitude of the direct echo and the evolution differs slightly. Tests on tubes with differents geometries and materials (glass tube of square section and M.P.M. circular tube) gave similar results. These first results show that it is possible to measure the gas rate in a diphasic flow by acoustic technic.

The highest measurements frequency were better adapted to determine, in this configuration, the volumic gas rate.

6. Thanks

To the "Société Européenne de Propulsion, Division Grosse Propulsion à Liquides", 27270 Vernon France.

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