Sound transmission study on liquid foams

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The possibilities for measuring the mean bubble diameter of liquid foams by sound transmission were investigated. Three systems were considered: a syntactic foam consisting of water and polystyrene spheres, an analogous syntactic gallium foam and lead foam expanded with a blowing agent. It was found that sound is transmitted through the foam only below a cut-off frequency which is related to the mean bubble diameter.

1. Introduction

In-situ observation of metal foam generation is highly desirable because it allows identification of the mechanisms responsible for bubble generation and decay. X-ray radioscopy was recently used for this purpose [1]. This method yields high-quality information about the internal structure of foams with excellent spatial and time resolution. For some applications, however, an X-ray source might not be usable. An experiment which is currently being designed for the International Space Station [2], e.g., might require a lighter and more compact device for measuring liquid foam parameters, namely the local density and the mean bubble diameter of foams. In this study we evaluated sound transmission. In a first step syntactic foams were prepared. These consisted of a packing of mono-disperse polystyrene spheres of various diameters which were infiltrated either by water or by liquid gallium metal (m.p. 31°C) and have the advantage of a defined pore diameter. In a second step PbSn30 alloy (m.p. 185°C) was foamed using the powder compact technique [3].

2. Theory

From optics it is well known, that particle size strongly affects scattering and absorption of light passing through heterogeneous systems. Mixtures such as oil/water emulsions can be both transparent and intransparent in different wavelength regimes. This effect can be used to measure mean particle sizes by analysing the wavelength dependence of the absorption coefficient. The situation for acoustic waves passing through a gas/liquid mixture, e.g. a metallic foam, can be considered to be quite similar. A particle size dependent "cut-off frequency" is expected. This allows the determination of the mean bubble size. Moreover, a pronounced dependence of sound velocity in gas/liqid mixtures on the relative fractions of the two phases is known. According to Wood (1941) and Urick (1947) the sound velocity in mixtures and suspensions is controlled by the mean density ρ and mean compressibility κ. If ϕ_j are the volume fractions of the various dispersed phases and ρ_j, κ_j their corresponding specific properties, the resulting sound velocity c will be (Urick equation) [5]:

$$c = \frac{1}{\sqrt{\kappa\rho}}; \kappa = \sum_j \phi_j \kappa_j; \rho = \sum_j \phi_j \rho_j$$

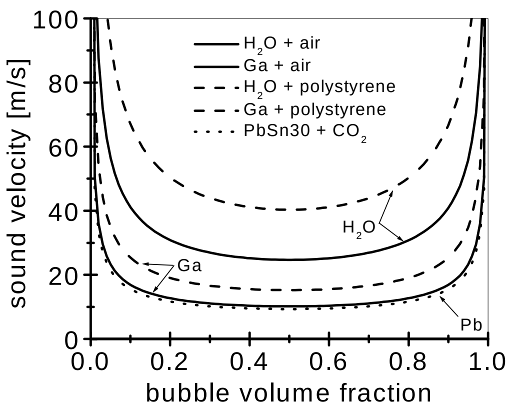

Figure 1. Sound velocity for various systems as a function of density.

Because in a gas/liquid-mixture the mean density ρ for nearly all volume fractions ϕ is determined by the liquid density ($\rho_{gas} \ll \rho_{liquid}$), whereas the mean compressibility κ is determined by the gas compressibility ($\kappa_{gas} \gg \kappa_{liquid}$), the sound velocity becomes very low and Eq. (1) can be approximated by $c \approx (\kappa_{gas}\ \rho_{metal})^{-1/2}$ for intermediate densities, i.e. $\phi_i \approx 0.5$. For a water/air mixture (ϕ_{air}=0.53), e.g., sound velocity is c=22 m/s, which would result in a cut-off frequency of c/D=22/0.001 s^{-1} = 22 kHz for a mean bubble size D= 1 mm. Figure 1 shows the density dependence of sound velocity for the various systems considered in the present paper.

This density dependence of sound velocity could be used to determine the local density of a foam provided that it were in the range of a significant slope of the curves. In the present study, however, we measured the density of the system, i.e. the coefficients ϕ_i directly, and calculated c using Eq. (1) based on values for κ_i and ρ_i taken from the literature. As our syntactic systems had bubble fractions between 50 and 65%, the lead foams between 50 and 80%, c depends only weakly on the precise values for ϕ_i.

Finally it should be noted that in all these considerations more complicated acoustic effects due to viscosity or acoustical resonance are neglected.

3. Experimental

3.1 Sample preparation

Syntactic foams were prepared in a cylindrical container by first filling polystyrene spheres into it, closing the container with a lid containing a small inlet and then pouring the liquid into it while simultaneously vibrating the container to remove air bubbles. Liquid gallium was processed under an argon atmosphere to prevent oxidation.

Lead foams were prepared by mixing 70% Pb and 30% Sn powder, adding 2% $PbCO_3$ and extruding the mix to a wire of 10 mm diameter at T=275°C [4]. This wire was foamed at temperatures above 350°C at which the blowing agent released CO_2 and formed a foam with a fairly uniform porosity.

3.2 Sound transmission measurements

For the three systems considered different set-ups were used as shown Figure 2. In all cases a delta-shaped pulse was created by a hammer. The signal was allowed to propagate through the foam and was then picked up by an acoustic sensor (marco ps/ks/11, linear characteristics from 100 Hz to 400 kHz). The signal was recorded and Fourier-transformed to obtain the transmission spectrum.

Water-based foams were investigated with the sensor immersed in the foam (a). The advantage of this is the absence of any concurrent sound transmission through the container walls. For Ga-based foams two elastic membranes were used to prevent the signal from propagating through the walls of the (plastic) container. The Pb foams, finally were allowed to expand freely, i.e. no container walls were present at all. However, but some sound transmission through air was recorded.

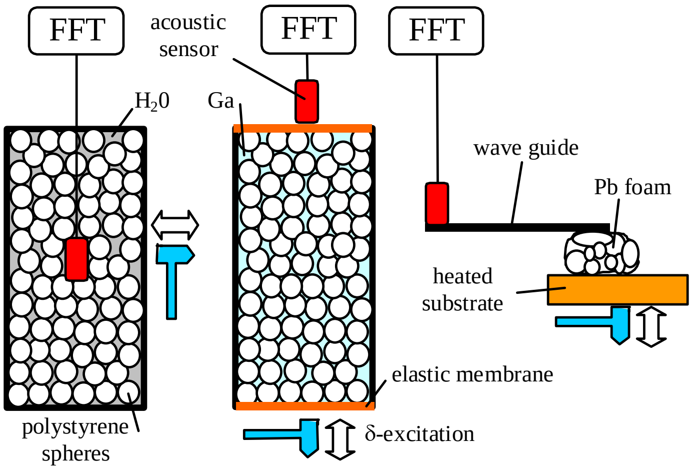

Figure 2. Experimental set-up for three different systems.

4. Results and discussion

From the sound transmission spectra cut-off frequencies were determined. This was not a straight-forward procedure as the onset of sound transmission is not well defined in many cases. For the current study an intuitive approach was chosen by defining the cut-off frequency as the point at which the intensity had risen to 5% of the peak value.

The cut-off frequency determined for the different foams is shown in Figure 3a as a function of c/D. This representation allows to compare foams of different materials, densities and pore sizes in one graph. One obtains a near-linear relationship for all the systems. This shows that the cut-off frequency indeed is a universal measure for bubble sizes. The different sound velocities in the various foams were taken account of by plotting c/D. The disadvantage of this plot is that different foams of one type occupy only a small region of the range of the x-axis. An equivalent but slightly more illustrative representation can be obtained by eliminating sound velocity. For this the axes are inverted and multiplied with c. The resulting wavelength vs. bubble diameter plot can be normalised with respect to the largest bubble size of each class of foams in order to distribute all values evenly over the x-axis. This plot, shown in Figure 3b confirms the view that foams from different materials and with different densities and pore sizes can be treated on an equal footing.

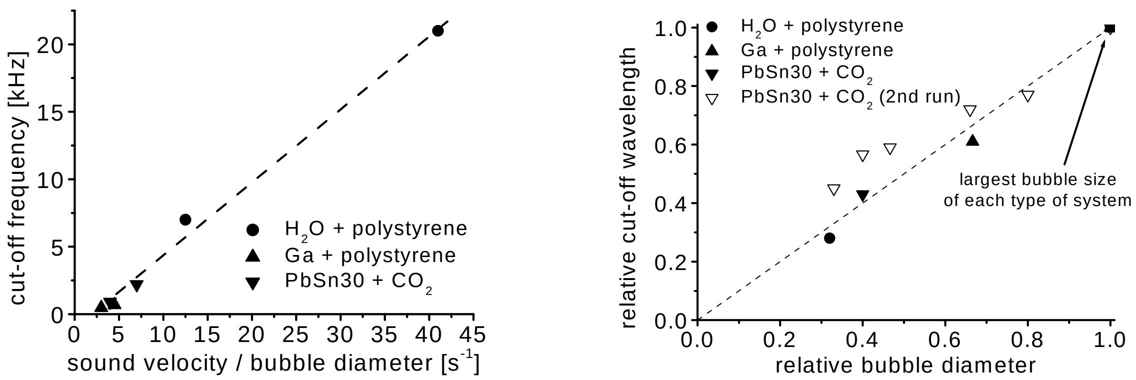

Figure 3. Cut-off positions for various foams. a) ν(c/D) b) $\lambda_{rel}(D_{rel})$

As the purpose of the work was to investigate „true“, i.e. statistical foams, a closer look has been given to lead foams. Various pieces of foamable precursor material, i.e. extruded mixtures of PbSn30 and $PbCO_3$ powders, were foamed at different temperatures. During foaming the cut-off frequency was continuously monitored. Qualitatively one observes that the cut-off frequency is decreased as the foaming process advances and the bubbles grow. As we do not know the time development of the bubble size we cannot determine the relationship D(v) at the moment. However, as the foaming process came to an end we cooled down the resulting foams and cut them open for a determination of the average pore size. It was found that higher foaming temperatures lead to larger final pore sizes in this system. This allows us to explore the dependence of the cut-off wavelength (determined from the cut-off frequency and the sound velocity calculated using the Urick relation) from the average pore size. The corresponding results are shown in. Figure 4.

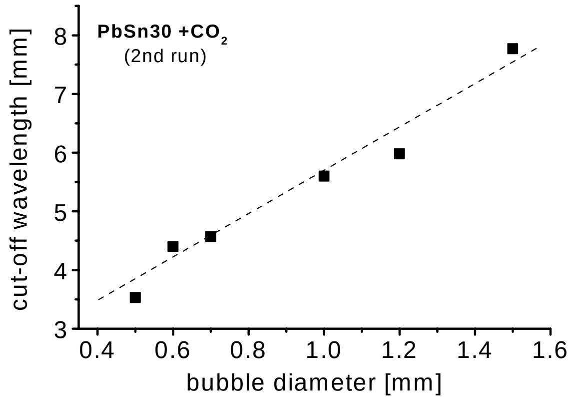

Figure 4. Cut-off frequency for various liquid lead foams with various final cell sizes.

Quite clearly the relationship discussed above is found again. The bubble diameter of lead foams can be derived from the cut-off wavelength of the foam.

5. Summary

It was shown that ultrasound transmission can be used for measuring the average cell size of liquid metallic foams in-situ. Measurement of sound velocity will be one of the future steps to obtain information about the local density of a foam. Moreover, application of these principles to liquid zinc and even aluminium foams is considered.

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