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Applications of Acoustic Cavitation to the Petroleum Industry: Bubble Sizing and Sonochemistry

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The ability to detect and make measurements on gas bubble populations in liquids has many applications within the petrochemical industry. For example, bubbles grow by the exsolution of gas, which dissolved in the crude at reservoir conditions when the pressure is reduced during production. Knowledge of the bubble population is useful to transportation but is costly to obtain by current techniques. During drilling ubble detection in the mud may give early indication of the presence of high-pressure hydrocarbon zones.

Bubble detection has wider implications for the industry giving, for example, warning of cavitation inception and erosion in pumping devices, and attempting, in decompression studies, to assess the dangerous formation of bubbles in divers. Also the bubble population in the near-surface layers of the sea is extremely important to a number of processes. The oceans act as a huge reservoir of atmospheric gases - by conservative estimates, a thousand million tonnes of atmospheric carbon dioxide dissolves into them each year. Bubbles clearly introduce an asymmetry into this flux; trapping atmospheric gases on formation through wave action gas and actively pumping it into the sea during dissolution. In addition bubbles are extremely effective sources of sound. As a result oceanic precipitation may be measured using the acoustic emission from the bubbles created when rainfall impacts the sea. This technique is particularly useful for remote sensors when the expense of routing a ship through the area of the interference of the land mass on island-mounted weather gauges, make those techniques unsuitable. Indeed, there has recently been a call for undersea measurements of rainfall to calibrate satellite measurements. Sound is also very effectively scattered by bubbles so that ultrasonic communication requires a knowledge of the bubble population.

These last two examples illustrate how extraordinarily acoustically active bubbles can be, which arises for three reasons. Firstly the gas within the bubbles has an acoustic impedance very much less than that of the surrounding liquid so that the bubble wall is strongly reflective to sound. Secondly, the compressibility of the gas is very much greater than the liquid, so that when bubbles are present the sound speed is changed greatly from that of the bubbleless liquid. Thirdly, the combination of this gas compressibility with the liquid inertia makes the bubbles lightly damped oscillators at relevant frequences (eg. millimetre-sized bubbles resonate at kilohertz frequencies). At resonance the acoustic scattering cross-section of a bubble is about a thousands times its geometric cross-section. Therefore the resonant bubble presents a "larger target" for acoustic scattering than for optical detection. This, coupled with the fact that ultrasound signal can propagate in opague media, means that acoustic techniques are often more appropriate than visual ones for bubble detection. The high quantity of bubbles also means that the resonance can conveniently be employed to accurately size bubbles. The strong interaction at resonance invokes the exhibition of nonlinearity in the behaviour of a bubble producing harmonics, subharmonics, frequency mixing and so on.

The technique of insonating the bubble population with a fixed imaging frequency (ν_i) of megahertz order and a pumping beam, the frequency (ν_p) of which is swept, has been capable of finding radii to -3% by the detection of signals $\nu_i \pm \nu_p$ when the pump coincides with the breathing-mode resonance of a bubble.