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USING ULTRASOUND TO SEPARATE OIL, GAS, AND WATER

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Separating oil, gas, and water is a slow, and therefore expensive, process, especially if the gas bubbles and oil droplets are very small. Yet, with increasingly strict regulations on filtered sea water quality, it is a process of major importance to most oil and gas industry. Using customised ultrasonic devices, we have been able to drive microbubbles through saturated fluids, forcing the bubbles to cluster and form microfoams at equal distances. These microfoams were then driven out of the fluid. In this presentation highspeed photography footage of this process will be shown. Ultrasound-assisted separation is a cheap technique that may have applications on a much bigger scale.

1. Introduction

Separating oil, gas, and water is a slow, and therefore expensive, process, especially if the gas bubbles and oil droplets are very small. Yet, with increasingly strict regulations on filtered sea water quality, it is a process of major importance to most oil and gas industry.

Ultrasound is commonly used as an imaging modality [1], but it can also be used to create an interaction with particles [2]. It has been shown that particles with impedance mismatch to their surrounding medium and be forced to aggregate in specific locations or radiated towards a boundary [3].

Bubble and droplet translation in the direction of the sound field is caused by a primary radiation force resulting from a pressure gradient across the bubble surface. The translation is maximal in contraction phase. In a standing wave field, bubbles with resonance frequencies higher than the transmitted sound field aggregate at the pressure antinodes, whereas bubbles with resonance frequencies lower than the transmitted sound field aggregate at the pressure nodes [4].

In this paper, we investigate the separation of coated microbubbles, by subjecting them to low-amplitude ultrasound and recording their behaviour with a highspeed camera.

2. Methods

A schematic overview of our experimental setup for simultaneous optical observations during sonication is shown in Fig. 1 and has been more thoroughly described in [5]. A container was filled with 2.6 L tap water. The container was placed on an x—y-table on top of a DM IRM inverted microscope (Leica Microsystems Wetzlar GmbH, Wetzlar, Germany) with two objective lenses: a 506075 C-Plan 10× objective lens (Leica Microsystems Wetzlar GmbH) with a 0.22 numerical aperture and a 506236 N-Plan 50× objective lens (Leica Microsystems Wetzlar GmbH) with a 0.50 numerical aperture. A Mille Luce™ Fiber Optic Illuminator Model M1000 (StockerYale, Inc., Salem, NH, USA) was connected to an optic fibre with a 7-mm diameter leading into the water of the container. It was placed in line with the objective lens.

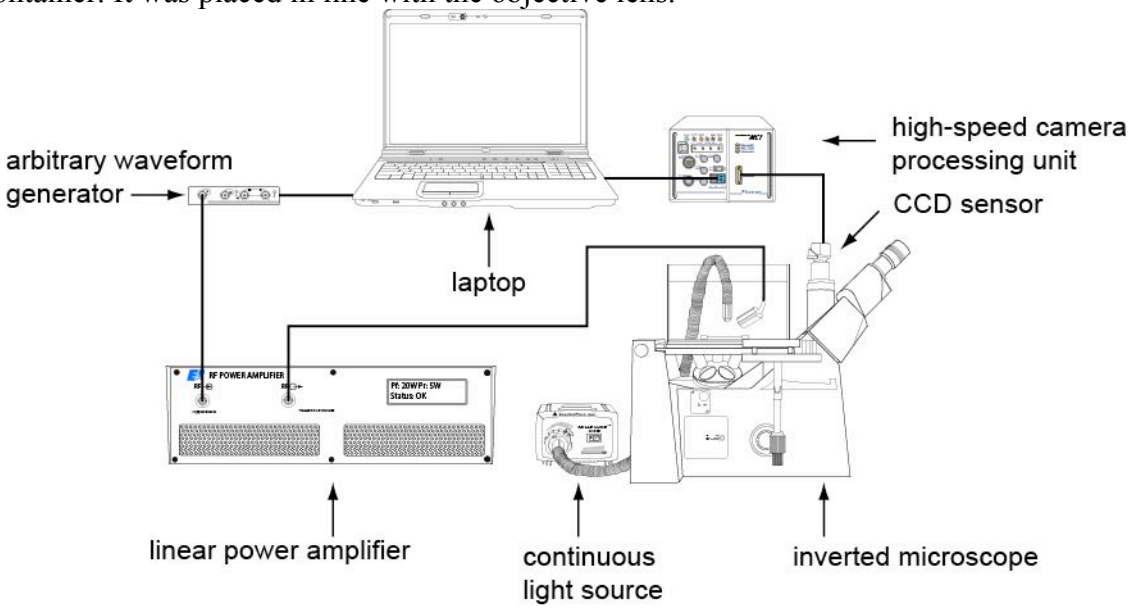

Figure 1. Schematic overview of experimental setup for simultaneous optical observations during sonication.

The charge couple device (CCD) of a FASTCAM MC1 high-speed camera (Photron (Europe) Limited, West Wycombe, Bucks, United Kingdom) was mounted to the microscope and connected to its processing unit, which was capable of recording images at 10,000 frames per second. The camera was controlled by a laptop computer.

A laptop computer triggered a DATAMAN-530 arbitrary waveform generator (Dataman Programmers Ltd., Maiden Newton, Dorset, UK), which was connected to a 2100L 50-dB RF power amplifier (Electronics & Innovation Ltd., Rochester, NY, USA). The power amplifier was connected to an undamped broadband single element transducer containing a Pz37 Piezo crystal (Ferroperm Piezoceramics A/S, Kvistgård, Denmark) with a centre frequency of 2.2 MHz. The design of the transducer has been described in [6]. Transmitted signals were typically continuous with frequencies in the range 1–10 MHz. The peak-negative acoustic pressures were determined using a PVDF needle hydrophone system with a 0.2-mm probe (Precision Acoustics Ltd., Dorchester, Dorset, UK) connected to a TDS 420A oscilloscope (Tektronix, Inc., Beaverton, OR, USA).

The ultrasound transducer was positioned in the container using a clamp stand, at a focal distance of 38 mm from the region of interest to be studied. The azimuth of the length axis of the

transducer relative to the North of the container was 37° and the elevation of the length axis of the transducer relative to the base of the container was 17°, as shown in Fig. 2.

Instead of using crude oil and natural gas, we used a commercial microbubble agent with very similar surface tension and viscosity as oil. DEFINITY® (Lantheus Medical Imaging, North Billerica, MA, USA) consists of C_3F_8 gas microbubbles with mean diameters between 1.1 and 3.3 μm, encapsulated by lipid/surfactant shells. Its resonance frequency had been measured to be 2.7 MHz [7].

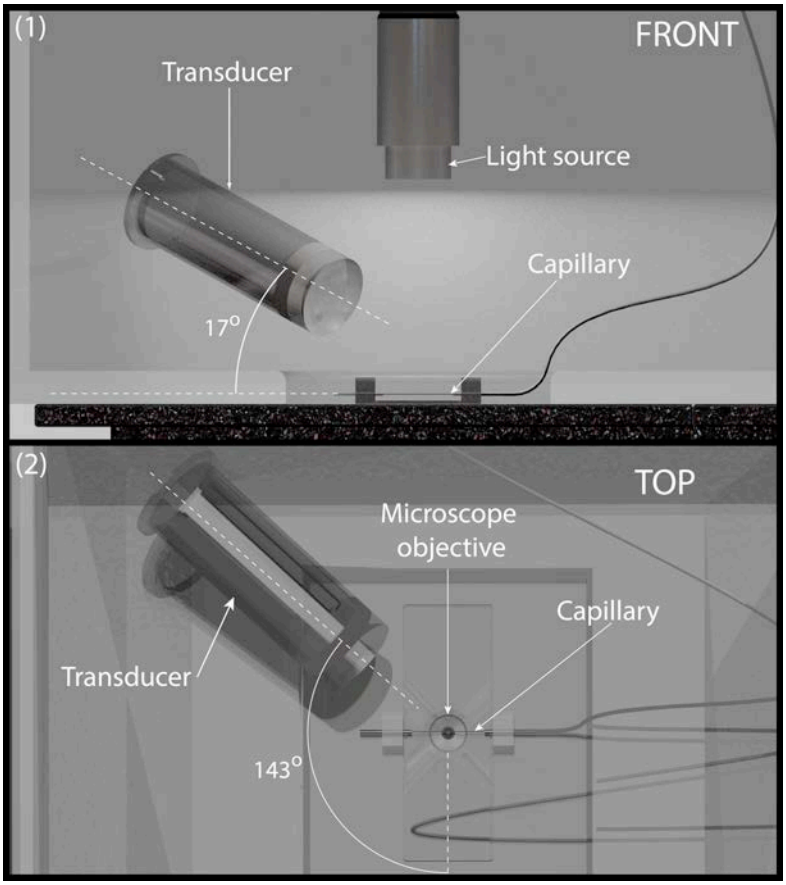

Figure 2. Rendered overview of sonication chamber for optical observations during sonication.

Diluted ultrasound contrast agent was inserted using a syringe into a microbore tube with a 0.51-mm inner diameter. The tube led to a CUPROPHAN® RC55 cellulose capillary (Membrana GmbH, Wuppertal, Germany) with a 200-μm inner diameter and an 8-μm wall thickness. The middle of the capillary coincided with the optical focus of the objective lens and with the acoustic focus of the ultrasound transducer, as shown in Fig. 2. The typical field of view using the 10× objective lens was 500 × 200 $(\mu m)^2$, whereas the diameter of the acoustic focus was greater than 5 mm. Hence, the whole field of view could be considered in acoustic focus. The capillary was positioned 2 mm from the base of the container. The flow speed of the ultrasound contrast agent through the capillary was manually controlled.

3. Results and Discussion

We observed the following stages of microfoam formation within a densely populated concentration of microbubbles. After the sonication started, contrast microbubbles collided, forming small clusters, owing to secondary radiation forces. These clusters coalesced within the space of a quarter of the ultrasonic wave- length, owing to primary radiation forces. The resulting microfoams translated in the direction of the ultrasound field, hitting the capillary wall, also owing to primary radiation forces.

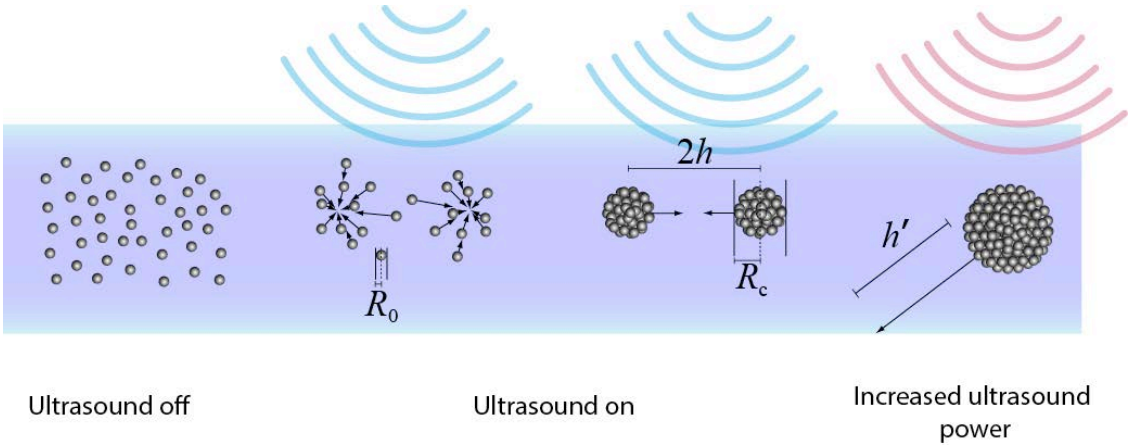

Figure 3. Stages of microbubble or partical agregation using low intensity ultrasound. A random distribution of particles is expected prior to sonication. Once sonication is started, the particles are attracted to eachother due to secondary Bjerknes forces and for small clusters. When sonication is continoued these clusters act as single particles and are subsequently attracted to eachother forming even larger clusters. Then, if need be, depending on the ultrasound power, these particles can be forced to the direction of a prefered boundary due to primary Bjerknes forces.

We have demonstrated that as soon as the bubble clusters were formed and as long as they were in the sound field, they behaved as one entity. At our acoustic settings, it took only seconds to force the bubble clusters to positions approximately a quarter wavelength apart. It also took only seconds to drive the clusters outside the field of view.

When sonicating microbubbles in high flow situations it was seen that the the particles separated into two dinstinct separate streams. One consitsted of microbubbles with a resonant frequency above the sonication frequency, and one consitsted of particles with a resonant frequency below the sonication frequency. This separation took less than 15 seconds to occour and could allow for separation and collection/extraction of these particles further down stream. By chosing an ideal frequency depending on the particle size, this could be done for gas and water particles in an oil stream. Further more, primary radiation forces could be used to push sediment to the boundaries of the vessle for preliminary low cost fine particle ‘filtration’ of the oil stream.

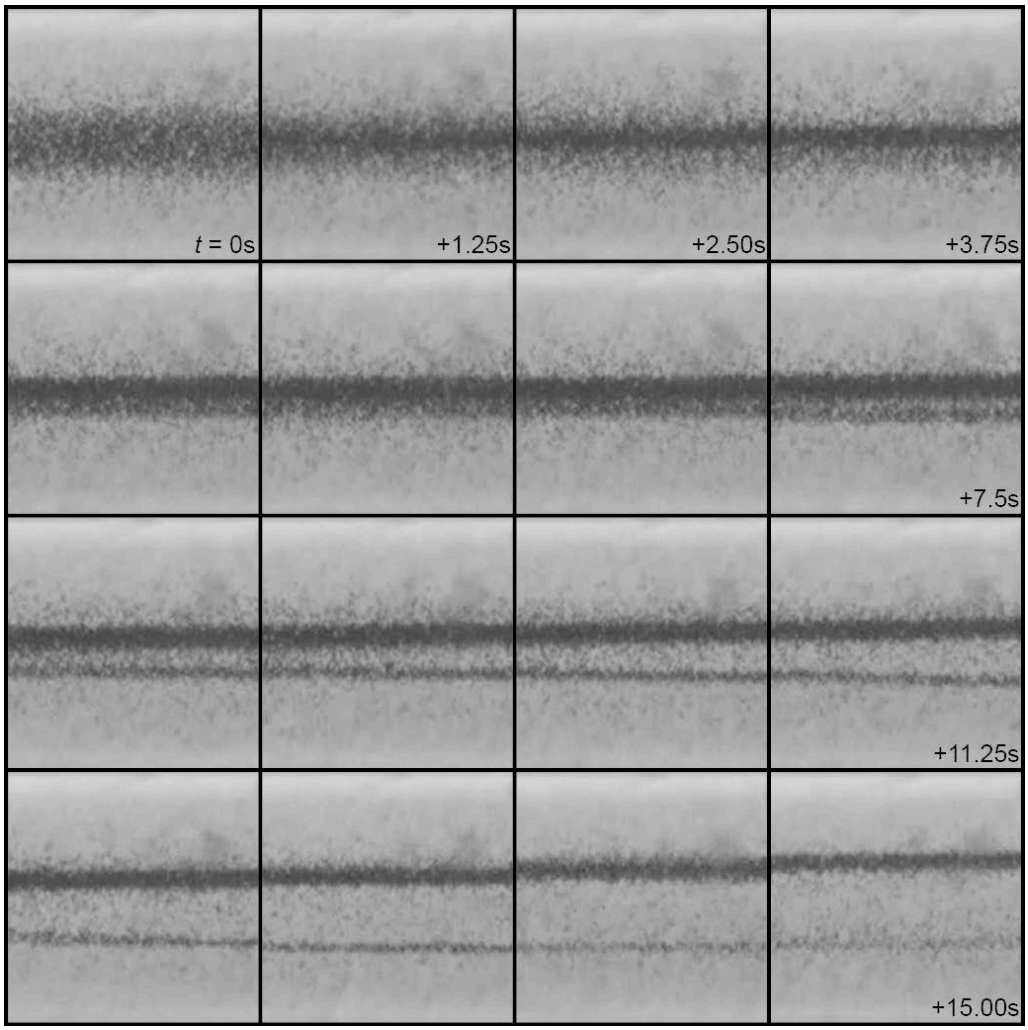

Figure 4. Forming two separate streams of microbubles in stream consists of larger microbubbles, one of smaller microbubbles. These streams corespond to microbubbles where their resonante frequencies are above and below the sonication frequency of 2.2 MHz. Each frame coresponds to 180×180 $(\mu m)^2$.

4. Conclusion

Ultrasound has been applied to can separate elastic gas-containing particles of different acoustic impedance using ultrasound in a static or flowing stream. Microfoams have been formed using ultrasonic equipment. These microfoams were driven out of the fluids mixture.

Highspeed photography demonstrates the microfoam formation mechanism. Ultrasonic separation is a promising tool for separation processes for oil and gas industry.

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