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REVIEW

Could the study of cavitation luminescence be useful in high dilution research?

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Cavitation in agitated liquids has been discussed for over five decades as a phenomenon that could play a role in the appearance of structural changes in the solvent of potentised dilutions. However, its lack of specificity as well as the absence of experimental confirmation have so far confined the idea to theory. The light emission associated with cavitational bubble collapse can be used to detect and study cavitation in fluids. The phenomenon has been extensively studied when driven by ultrasound, where it is called sonoluminescence. Sonoluminescence spectra reflect extremely high temperature and pressure in the collapsing bubbles and are parameter sensitive. This article tries to examine whether, despite objections and difficulties, the detection or the study of cavitational luminescence in solutions during potentisation could be useful as a physical tool in high dilution research. *Homeopathy* (2017) **106**, 181–190.

Keywords: Cavitation; Hydrodynamic luminescence; Sonoluminescence; High dilution; Potentisation

Introduction: cavitation and potentisation

Cavitation bubbles are gas or vapour bubbles (typically 20–50 μm, but sometimes much larger) caused by the sudden depressurisation that can occur in fluids submitted to turbulent flow (hydrodynamic cavitation) or to sound or ultrasound (acoustic cavitation).[1]

Bubbles form when pressure falls below the fluid vapour pressure, swell until they reach a maximum radius, before collapsing when pressure increases again. In fact, due to the inertia of the bubble, the radius continues increasing past the minimum pressure, so that the collapse occurs within a few microseconds, followed by a number of rebounds (Figure 1) The rapid collapse of bubbles, whose wall velocity exceeds the speed of sound, creates a local concentration of pressure and a rise in temperature, which are intense enough to generate reactive species, increase chemical reactivity, melt metal particles and, in certain conditions, emit light.[1–4]

Circumstances of cavitation bubbles occurrence include shock waves or acoustic waves in water, as well as sudden pressure variation, as happens with the Venturi effect. According to the principle of mass continuity, flow velocity increases when the liquid flows through a narrower channel. In agreement with Bernoulli's law, pressure decreases as a function of speed. A constriction therefore creates a drop in pressure, which can become negative. This is the principle that makes a water aspirator work. Downstream from the constriction, as the diameter increases again, pressure increases again. A natural Venturi effect can be observed on mountain tops, where the wind blows stronger and clouds form with diminishing pressure and then clear up downwind. Venturi tubes (Figure 2) or other types of constricted flow create cavitation bubbles that collapse downstream from the constriction and have been used for the study of cavitation and bubble collapse.[5–8]

Hydrodynamic cavitation also occurs in the natural world: for example, the sharp sound produced by the 'snapping shrimp' *Alpheus heterochaelis* when it shuts its big claw, does not come from the shock of the two jaws of the claw against one another, but from the collapse of a single cavitation bubble created by the sudden and fast flow of water.[11] Cavitation was first identified as a cause of corrosion of the metal propeller blades of warships in the late 19th century.[9,10]

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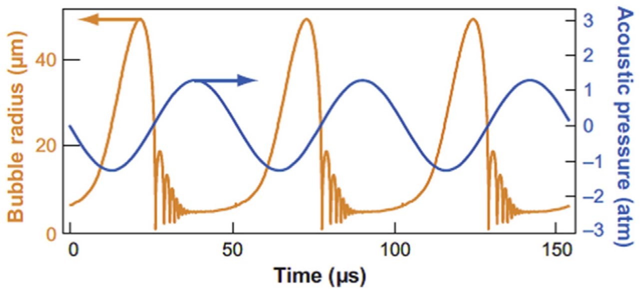

Figure 1 Calculated model of the non linear radial response of a bubble driven by a sinusoidal acoustic wave at assumed equilibrium conditions. The bubble radius increases with diminishing acoustic pressure. As the acoustic pressure wave enters the compression phase the bubble radius first continues to increase inertially, then peaks and suddenly collapses, followed by a few rebounds. The very short (less than 50 ps) light pulse that constitutes sonoluminescence is produced during the final stage of the collapse, just before the radius reaches its minimum. Reproduced from[51] Suslick KS, Flannigan D. Inside a Collapsing Bubble: Sonoluminescence and the Conditions During Cavitation. Annu. Rev. Phys. Chem. 2008. 59.659–83 (with permission)

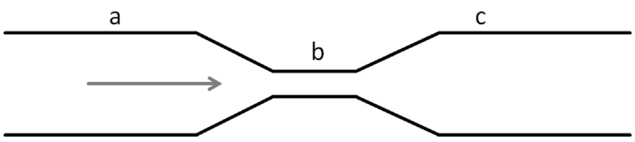

Figure 2 Diagram of a Venturi tube. Diameter is usually centimetric. Supposing that the liquid flows from left to right, pressure decreases and velocity increases as the liquid goes from *a* through the constriction *b*, then pressure increases and velocity decreases as the diameter of the tube goes back to the original dimension in *c*. In a cavitation setting, luminescence from bubble collapse appears in *c* a few centimetres downstream from b.

The first mathematical model of bubble collapse was proposed by Rayleigh in 1917.[12] It predicted that maximum pressure during bubble collapse would rise to thousands of atmospheres. Due to adiabatic heating as the bubble radius decreases, temperature inside a bubble can reach at least ca. 4 to 5000 K.[1]

Research on cavitation has been conducted in majority with ultrasound sources of acoustic waves, which provide reliable stable sources of periodical stimulation or maintenance of bubble formation and collapse. Long before characteristics of collapsing bubbles were known, their activating properties on chemical reactions were exploited and studied as sonochemistry. Sonochemical application are varied, from simple uses, such as the cleaning of metal objects by ultrasonication or the treatment of wastewater, to a wide variety of laboratory or industrial applications. Ultrasound can be used, not only as activators or catalysers of chemical reactions, but also in the manufacturing of nanostructured industrial or biomedical materials such as metal surfacing or protein microspheres that could be used, for example, as drug delivery systems.[1–4]

In 1966, G. Boericke and R. Smith suggested that cavitation could play a role in the homeopathic dilution and agitation or succussion process known as 'dynamisation' or 'potentisation'. These authors used, not only the traditional succussion, but also ultrasound sonication as a homeopathic preparation procedure, and explicitly mentioned cavitation as a possible factor in potentisation obtained by either traditional succussion or sonication.[13] Their hypothesis was based on similarities that they observed between nuclear resonance imaging (NMR) spectrograms of solutions potentised in the traditional homeopathic way and spectrograms of matching sonicated solutions, compared to spectrograms of control or non-agitated solutions.[14] In their view, both sonication and traditional homeopathic agitation can provide through cavitation the energy needed to modify the physical structure of water, a hypothesis proposed by G.O. Barnard shortly before. Barnard formulated the idea that, with a sufficient input of energy, specific information can be 'recorded' in the solvent through the generation of self-replicating water polymers.[15]

By finding in cavitation an 'engine' to Barnard's general hypothesis, Boericke and Smith helped give weight to the concept that the solvent keeps an 'imprint' or a structural modification of some sort, later nicknamed 'memory of water', which has since remained a central concept in high dilution research. Many authors have offered theoretical proposals about the form in which solute-specific 'information' could be 'recorded' and stabilised or self-replicated in the solvent in the absence of the original solute,[16–27] (recent reviews in[28,29]). The most frequently discussed models include (from the most to least local) 'cage' or 'shell' clathrates or solvatation-like supramolecular nano-superstructures including nanobubbles around original solute molecules, multiple solvent clusters whose general structure or distribution might be nucleated or influenced by the solute, and quantized coherence domains of electromagnetic nature.

There is now strong experimental evidence that solutions potentised at dilution levels exceeding the theoretical limit of presence of solute molecules determined by the Avogadro number exhibit structural changes compared to controls. A particularly consistent body of evidence built over several decades by J-L. Demangeat in the same model of nuclear magnetic resonance study of water proton relaxation, as well as numerous other technical approaches by other authors, including, UV-spectroscopy, thermoluminescence, dielectric dispersion, conductivity, fluorescence microscopy, solvatochromic dyes, converge to substantiate the existence of structural specificities in high dilutions and point towards the existence of aqueous nanostructures. The presence at nano-size level of so-called impurities – in fact a misnomer as there is no such thing as pure water – especially silica, as well as that of nanobubbles is thought to contribute to the formation and stabilisation of specific solvent structures.[26,27,30–40]

However, the experimental evidence is not specific enough to disprove any of the proposed models as opposed to the others. There are converging if controversial clues that nanoparticles of solute might persist in the solvent even at high potencies. Solute molecules or nanoparticles could gather at surfaces and be preferentially aspirated when pipetting, or clustered nanobubbles might trap solute molecules and prevent their physical disappearance from