Review by Dr John Ferreirinho

Comments on acoustically pumped shock wave generation proposal

The design outlined in this proposal is ingenious and seeks to exploit the advantages of a large centrifugal acceleration field in a rapidly rotating and resonant system (several thousand rpm) to scale up the generation of shock waves previously generated on a much smaller scale in direct sonoluminescence as reported in *Scientific American* in 1995.

On the basis of an initial perusal, the proposal is in my opinion worthy of serious consideration with regard to further exploration and feasibility study. I believe it has good prospects of success in achieving the goal of scaling up the shock wave generation process by one or two orders of magnitude in linear dimension without the need for any radical revision of the design.

Some more detailed comments (opinions) are outlined below.

The introduction of the large centrifugal field has three advantages:

Advantages:

(1) It raises the resonant frequency of the oscillations of the liquid in the rotating U-tube by a factor of about 200 over those which would obtain with only the earth's gravitational field acting as the restoring force for the oscillations. This would be a convenient driving frequency for a sound field used to pump the shocked bubble. The term 'pump' is used here in the sense of laser and mechanical or electronic parametric amplifier operation, since the devices considered in this proposal are somewhat similar to parametric amplifiers in their basic operation.

(2) The quality factor of the oscillations is greatly increased by a similar factor of about 200, so that the oscillations should have a sharply defined resonant frequency , further amplifying the intensity of the driving sound field at resonance. If it assumed that viscous shear dissipation of acoustic energy in the oscillating water column is the dominant loss mechanism for the acoustic pump energy , the Q factor of the resonant oscillations is found to scale as:

$$Q = \frac{\rho \omega r^2}{2\eta} \qquad (1)$$

where ρ is the liquid density, r is the tube radius, ω is the angular frequency of the resonant oscillation and $\eta$is the viscosity of the liquid (about $\eta = 0.1$ kg $m^{-1}s^{-1}$ for water at 20 ° C) The Q factor is in this approximation independent of the length of the tube.

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This may be expected to have much the same effect as the increase in the ambient liquid pressure discussed in connection with advantage (3) above. This extra assistance is not available at the larger scales , since the internal equilibrium pressure excess ΔP of a gas bubble scales as

$$\Delta P = \frac{2\gamma}{R} \qquad (2)$$

where γ is the surface tension of the liquid (about $\gamma = 0.07$ J m^{-2} for water) and R is the bubble radius. In scaling the process up, this may have the effect of partially negating some of the gain and improvement expected from the new design.

Another scaling consideration is that the temporal scaling of the shock wave generation process will in my opinion need detailed preliminary investigation in the early stages of the proposed project. Direct sonoluminescence is reported to involve generation of picosecond shock pulses when small bubbles (typically 1 to 10 μm diameter) are pumped with an ultrasonic sound field with a frequency of about 30 kHz.

It is likely that a complex and non-linear resonance occurs between the driving sound field and the dynamics of these small gas bubbles. The scaling of these characteristic times to much larger bubbles will need to be understood before the appropriateness of the proposed pump frequency (300 Hz in the present proposal.) can be verified.

2. The advantages of the proposal are purchased at the expense of the introduction rapidly moving mechanical components. This is likely to complicate and prolong the development process.

3. The possible practical applications of this technology (eg toxic waste disposal) are likely to require a further stage of development. Like most innovative research proposals involving research into newly discovered phenomena, the practical and commercial potential of this proposal is likely to be quite long term (typically a decade or more to commercial exploitation).

Conclusion:

The proposal has a good prospect of achieving a one to two order of magnitude increase in the size of shocked gas bubbles within about three to five years of commencement if adequately funded. My rough estimate of the total research and technical labour requirements to implement the propsal to such a stage would be about 20 to 30 person-years.

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Note: The opinions expressed here are solely my own. I wish those involved in this worthy proposal every success in their future endeavours.

J. Ferreirinho.

Post-script

The above comments ignored the effect of the constriction in the U tube incorporated in the design of the shock wave apparatus. This should act as an impedance transformer to improve the energy coupling between the driving sound field and the gas bubble. Increased coupling will however reduce the quality factor of the liquid oscillations. The incorporation of this impedance transformer segment should therefore result in improved performance, but the improvement may be more modest than a simple consideration of coupling factor alone would indicate.

Dr J Ferreirinho
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