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Towards a reference ultrasonic cavitation vessel. Part 1: Preliminary investigation of the acoustic field distribution in a 25 kHz cylindrical cell

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Abstract

The acoustic field produced by a 25 kHz, 25 l cylindrical sonochemical processing cell has been characterised systematically using a sonar hydrophone, with the aim of establishing it as a reference test bed on which future investigations into acoustic cavitation activity may be based. Data acquired at sonication levels up to 500 W have shown that though significant cavitation activity is generated throughout the vessel, the acoustic field generated is reproducible, typically to ±12%. The increases in acoustic pressure are shown to be nonlinear with applied power, suggesting an intermediate optimum level for future study.

Keywords: Ultrasonic measurement; Hydrophones; Cavitation; Sonochemistry

1. Introduction

The harnessing of high power ultrasound is becoming more widespread in both research and industrial contexts. Frequently, the applications being considered are driven by the associated phenomenon of acoustic cavitation, and to assist its control and optimisation there is an increasing demand for characterisation techniques that can provide spatial and temporal information on the cavitation process [1]. Acoustic cavitation may briefly be described as the inception, growth and oscillation of vapour or gas bubbles in a medium under the influence of ultrasound [2–4], giving rise to a range of physical, chemical and biological effects [5–8]. Measurement methods are needed for reasons of determining process efficacy, quality, and even safety, and are essential when attempting to scale up processes from laboratory bench to pilot plant on an informed basis [9].

Hitherto, a vast range of measurement techniques has been applied [10,11]. However, to date, no standardised measurement methods exist [12]. An accessible method is acoustic emission: cavitating bubbles form secondary sources of sound, whose emissions can be detected using piezoelectric techniques, and the resulting spectrum contains significant information about the cavitation process [4,13,14]. In recent years, these techniques have been applied to characterise the cavitation activity generated by commercial ultrasonic cleaning vessels, sonochemical horn processors and physiotherapy devices [15–18].

However, to allow validated measurement techniques and sensors to be developed and tested in a systematic manner, it is essential to have a test facility whose acoustic performance is well characterised and reproducible. Such work has been carried out using a standard commercial ultrasonic cleaning vessel at NPL [19]. The use of an 'off the shelf' vessel in that study had some limitations: in particular, there was a lack of controllability of the vessel output, and the resulting acoustic field distribution was complex and ultimately of limited reproducibility. The establishment of a new bespoke facility provides greater

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potential to be used as a reference in the long term. The initial characterisation of the new facility at NPL is the subject of this paper, with the first aim being to establish and understand the acoustic field distribution to provide data which will underpin future cavitation investigations.

2. The reference vessel

A number of features of a cavitating ultrasonic system can be identified which are desirable in seeking to establish it as a reference vessel:

- It should generate a reproducible, predictable and relatively simple acoustic field (and hence, cavitation distribution), generating localised pressure and cavitation maxima remote from solid–liquid interfaces.
- It should be variable over a range of output levels, from below the cavitation threshold to the generation of high acoustic pressures and accompanying violent inertial cavitation.
- It should be of sufficient size to generate a large spatial variation in cavitation activity.
- It should include control and monitoring of the properties of the propagation medium.
- It should be useable with a diverse range of cavitation monitoring techniques.

The vessel currently being established at NPL is based on a model P1800-25 Ultrasonic Processing Cell, produced by Sonic Systems (Somerset, UK), and developed from an initial design by Accentus, UK, for the application of high power ultrasound to crystallisation processes. The vessel is shown in Figs. 1 and 2. Its specification is as follows:

- Cylindrical profile: 330 mm high, internal diameter 312 mm, volume of around 25 l, with a hard-chromed inner surface to minimise the occurrence and effect of trapped air at the transmitting surface.
- Thirty 25 kHz PZT transducers, each 50 mm in diameter, epoxy-bonded to the vessel wall and radiating into the central volume.
- Transducers are distributed evenly in three horizontal rows of 10 devices, with the middle row positioned at the 'half height' position of the cylindrical part of the vessel.
- Three generators (one per row), supplying up to 600 W of electrical power each, so the maximum power density available is 72 W/l: transducers excited via 100%, 100 Hz modulation 25 kHz burst.

The vessel is connected to a water preparation supply and drainage facility [19], with the addition of a temperature control system (Grant, UK), which allows the temperature of the medium in the vessel to be varied in the range 10–60 °C, and the initial dissolved oxygen content to be varied in the range 0–8 mg l^{-1}. The vessel is positioned beneath a three-axis positioning system (Time and Precision, Basingstoke, UK), which has a positional resolution of 0.05 mm, and a movement speed of 20 mm s^{-1}. The operation of the reference vessel and positioning system is under RS-232 control.

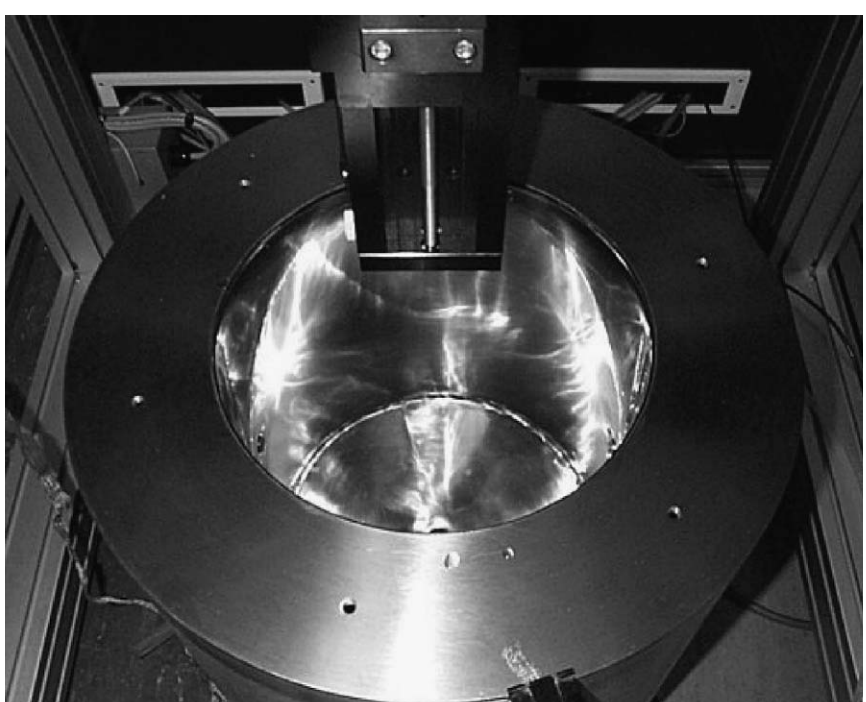

Fig. 1. Sonic Systems reference vessel.