

ULTRASONICS AS AN ALTERNATIVE TO CHLORINE FOR INHIBITING BIOFOULING

Chlorine is used to inhibit biofouling in once-through cooling water (heat exchange) systems of electrical power plants. Because the discharge water contains unused chlorine and its reaction products that are toxic to a number of aquatic organisms, ultrasonics is being investigated as an alternative.

INTRODUCTION

Power plants that use estuarine or marine cooling water need to control biological fouling (biofouling) of their heat exchange systems. Two distinct types of biofouling — macrofouling and microfouling — are observed, depending upon the water flow velocity. Macrofouling (barnacles, hydroids, and other organisms) occurs in such areas as precondenser approach conduits and intake structures, where flow velocities are less than a meter per second. Because the low flow velocities are optimal for their growth, some hydroid species, such as *Garveia franciscana*, may form very large, dense mats that periodically slough off from the walls of intake structures, severely restricting the flow of cooling water by clogging condenser grids. Flow velocities above 1 meter per sec-

ond inhibit the attachment of most macrofouling organisms but do not prevent microfouling (accumulation of bacterial slime), which is a serious problem in condenser tubes because it reduces the efficiency of the heat exchange process.

Chlorine is widely used to control both macrofouling of the precondenser areas and microfouling in the condenser tubes. However, because chlorine and its residual by-products are toxic to many forms of aquatic life, an alternative to that biocide, such as ultrasound, is highly desirable. If ultrasound proves to be an effective antifoulant for precondenser areas, it could be combined with a mechanical condenser cleaning method (such as Amertap) to eliminate the need for chlorination.

This investigation explores the use of ultrasound to cause tentacle retraction in the colonial hydroid *Garveia franciscana* (Fig. 1), thereby preventing its feeding and inhibiting its growth. Retraction occurs at power levels that are much lower than those required to kill or dislodge the organism. Microvideo observation can be used to determine the intensity and frequency at which the organisms immediately respond, eliminating the need for extended studies of growth inhibition.

EXPERIMENTAL APPARATUS

Figure 2 is a schematic of the major components of the experimental apparatus. The electronic equipment includes a frequency generator, amplifier, oscilloscopes, voltmeters, and frequency counter to generate, monitor, and measure the electrical signals to the transducer (generator of ultrasound) and from the hydrophone (monitor of ultrasound). The test equipment is composed of an ultrasonic transducer, a hydrophone, a sample of the organism being tested, and an aquarium. The observational equipment consists of a microscope (10 to 80 times magnification), a video camera, a video tape recorder, and a color TV monitor.

EXPERIMENTAL PROCEDURE

A hydroid's tentacle contraction in response to ultrasound is easily observed. Figure 3a shows the hy-



Figure 1 — Secondary branch of *Garveia franciscana* showing feeding hydranths with fully extended tentacles (about 10 × magnification).

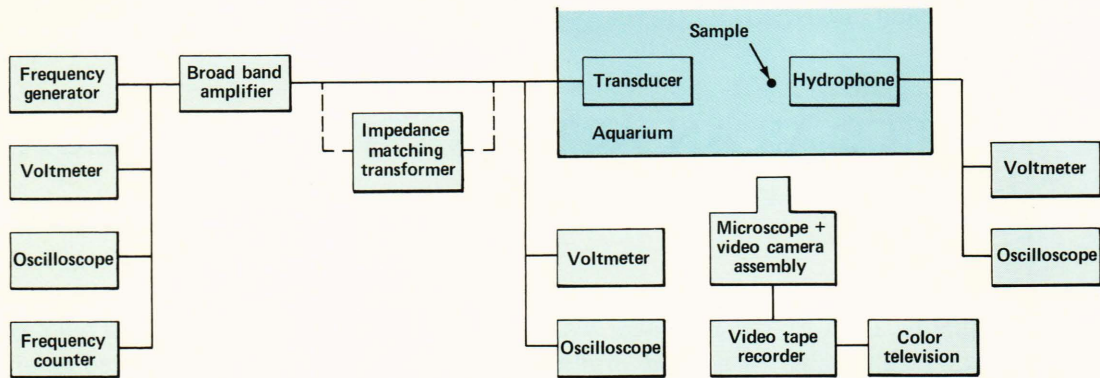


Figure 2 — Schematic drawing of the major components of the experimental apparatus.

dranths with their tentacles fully extended, before application of the ultrasound. Figure 3b shows the hydranths with their tentacles contracted in response to ultrasound. Note that the bodies of the hydranths are also contracted.

The following experimental procedure was used to determine the minimum continuous sound intensity required to cause 100% tentacle retraction at frequencies of 260, 440, 790, 1100, 1600, and 2000 kilohertz. A secondary branch was clipped from one of the stock cultures and attached to a glass microscope slide so that most of the branch extended above the top edge of the slide. It was mounted in the aquarium in filtered (1 micrometer filter retention) Parish Creek water at 10 parts per thousand salinity and 27°C. The colony was located approximately on a line between the centers of the sound transducer and the hydrophone 12 centimeters away from the transducer and within 0.5 to 1.0 centimeter of the hydrophone, which could thus measure the acoustic intensity at a point just behind the hydroid sample.

The transducer voltage was increased until the sound intensity was seen to have caused 100% retraction of all hydranths and was then returned to zero. Five consecutive exposures were made on each hydroid sample, with recovery periods of 20 to 30 minutes between each exposure; these exposures were enough to ensure that the tentacles of all the hydranths had reemerged. Following the fifth exposure, the sample was replaced by another. Three samples, each receiving five consecutive exposures, were tested at each of the six experimental frequencies.

EXPERIMENTAL RESULTS

A nested analysis of variance showed that there were no significant differences in the response levels among the five consecutive exposures for any hydroid sample at a fixed frequency. Thus, there is no short-term (less than 2 hours) physiological accommodation nor an increase or decrease in the response threshold of *Garveia franciscana* to ultrasound at frequencies between 260 and 2000 kilohertz. Table 1 lists the mean sound intensity needed to cause complete contraction of all hydranths at each of the test

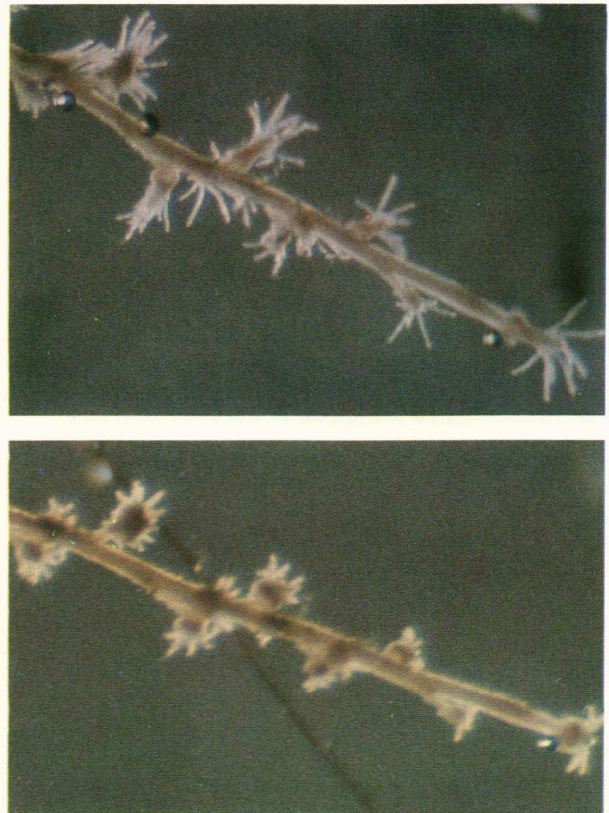


Figure 3 — (a) *Garveia franciscana* is shown without ultrasound. (b) The same section of *Garveia franciscana* with the hydrocanths contracted in response to ultrasound (magnifications about 10 \times).

frequencies. The intensity response was highly frequency dependent.

Close examination of the video tapes revealed that all of the hydranths within a particular sample retracted simultaneously. The contraction threshold occurred almost exactly at the sonic degassification level, which is the ultrasonic intensity at which dissolved gases in the water begin to come out of solution and form small bubbles. This threshold is a function of ultrasonic frequency, amount of dissolved gases in the water, water temperature, and the

Table 1—Mean sound intensity required to produce 100% contraction of all hydranths at each test frequency.

Frequency (kilohertz)	Mean Sound Intensity (watts per square centimeter)	Standard Deviation
260	0.6	0.10
440	1.6	0.70
790	1.6	0.37
1100	3.7	0.52
1600	4.3	0.52
2000	4.2	0.96

presence of particles that act as nuclei for bubble formation.

The actual mechanism that causes the organism to retract its tentacles is not known. However, the importance of gas bubbles in the biological effects of ultrasound has been described by W. Nyborg.¹ The coupling of ultrasound into the organism may be greatly increased by bubble formation on the surface or inside the organism. Bubbles will pulsate in the ultrasound, causing microstreaming within the organism that results in shearing stress on various cellular components.

Figure 4 shows the mean response level as a function of frequency. The standard deviation bars represent experimental variance in the organisms' response to sound. Greater potential error of sound intensity calibration may exist. Because the sonic degassification level should increase fairly linearly across this frequency range, a straight line was fitted to the data points using a least-squares regression program. This curve ($R^2 = 0.85$) clearly demonstrates that lower frequencies require less power to cause tentacle retraction in *Garveia franciscana*.

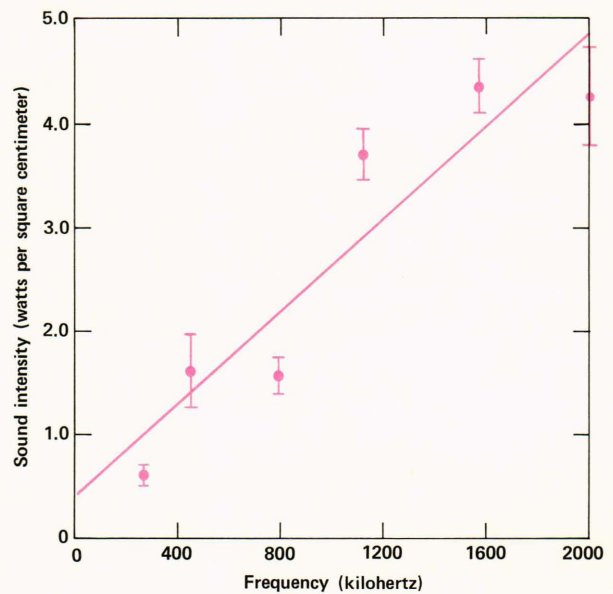


Figure 4—The mean sound intensity required to produce complete contraction of all hydranths at the six experimental frequencies. Bars represent one standard deviation.

The threshold response power requirement is approximately 0.6 watt per square centimeter at 260 kilohertz. Present pulse experiments indicate that duty cycles (sound on/sound off) as low as 0.2% are effective in preventing growth, when using above-threshold power levels.

REFERENCE

¹W. L. Nyborg, *Physical Mechanism for Biological Effects of Ultrasound*, HEW Publication (FDA) 78-8062 (1978).

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