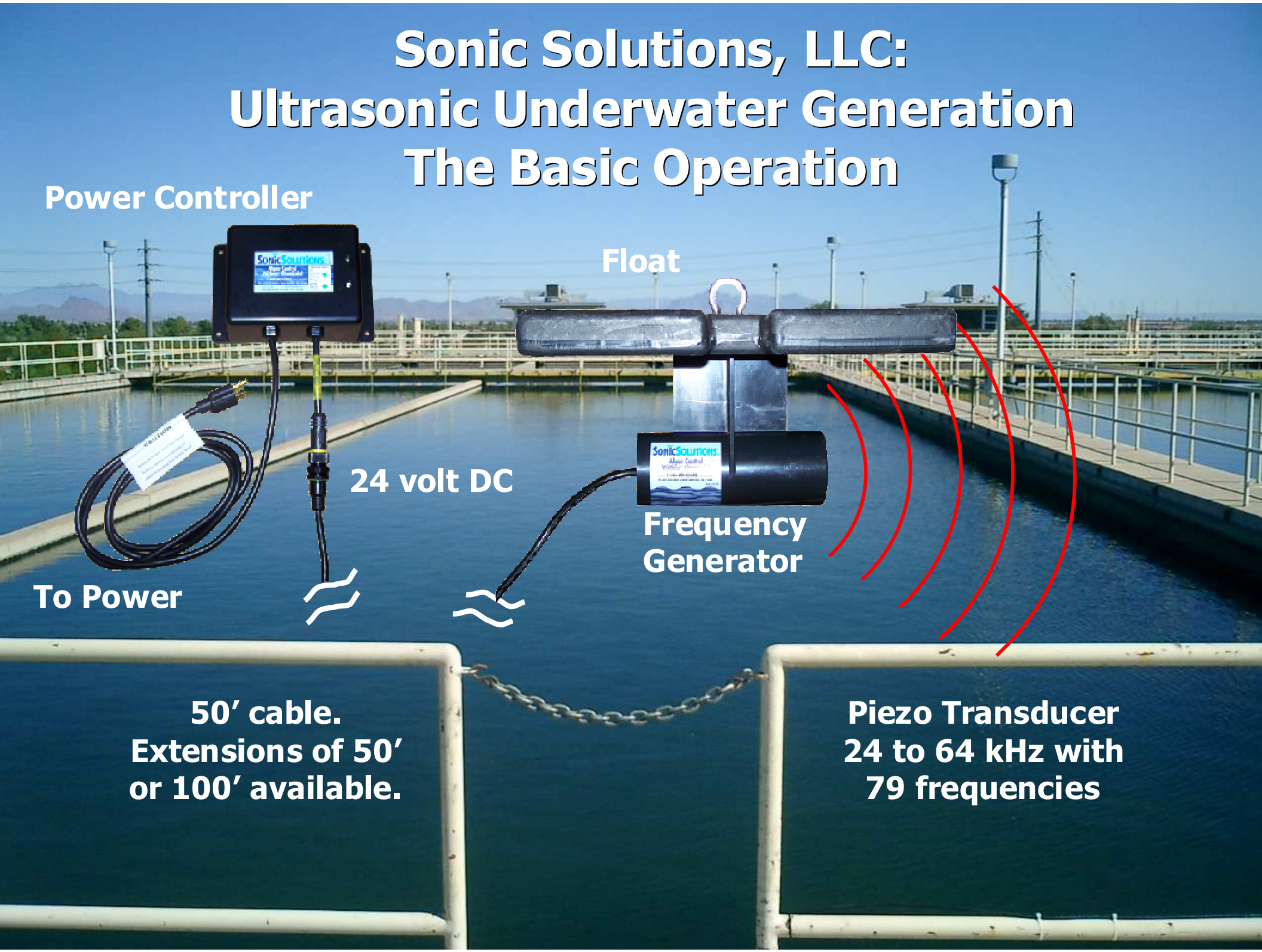
Applying Ultrasound Technology to Control Algae and Biofilm

George W. Hutchinson

AlgaeControl.US

Sonic Solutions, LLC:
Ultrasonic Underwater Generation
The Basic Operation

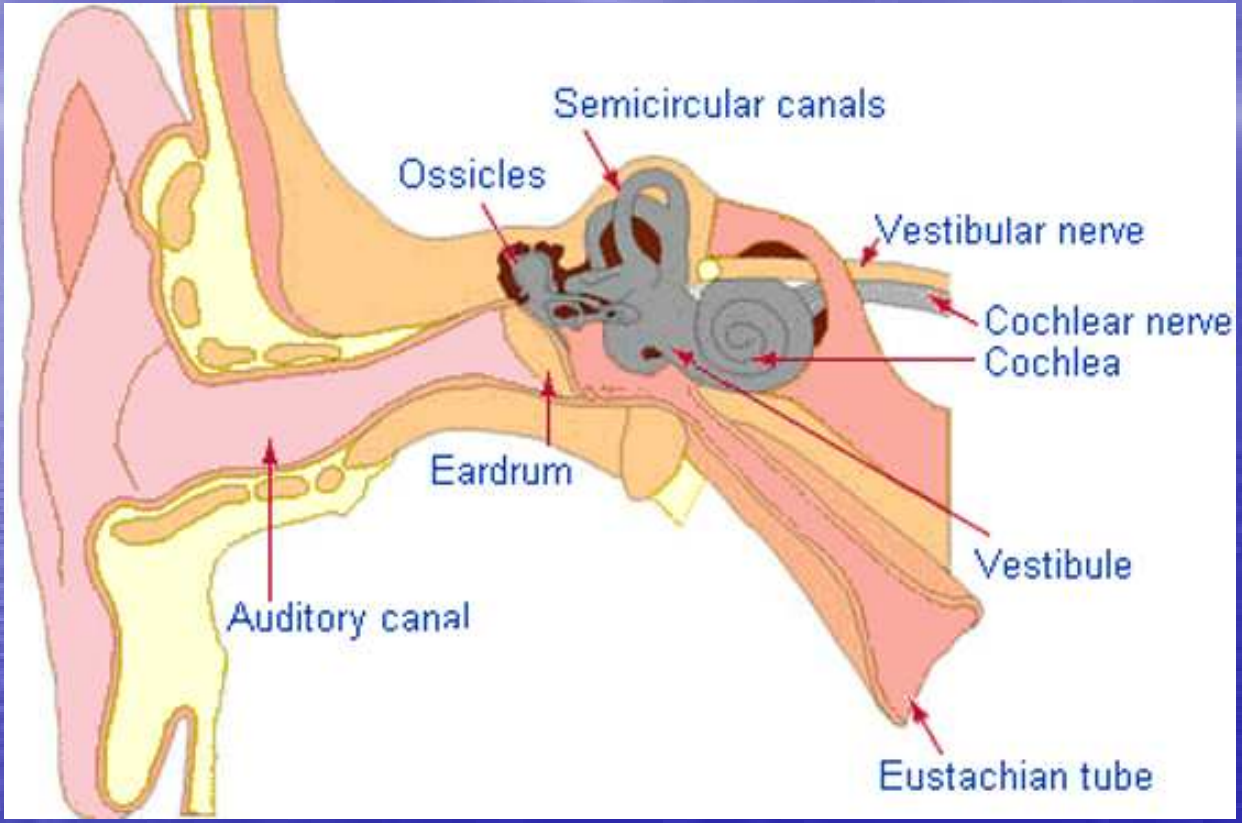


Understanding Ultrasound

"Ultra" basically denotes a sound that is beyond the frequency that can normally be heard in air by the human ear.

In air, your ear can hear sounds between 20 Hz and 20,500 Hz. The upper limit is set by the middle ear that acts as a high pass filter.

You Can "Hear" Ultrasound



If the sound vibrates the skull, the cochlear nerve will allow you to "hear" up to 200,000 Hz, an effect discovered by divers who were able to hear sonar pings at about 50,000 Hz.

Uses of Ultrasound

Medical:

- Lithotripsy of kidney stones
- HIFU: High Intensity Focused Ultrasound: non-invasive surgery
- Fetal Imaging
- Dental hygiene

Industrial:

- Metal and weld integrity testing
- Catalytic reaction enhancement
- Sludge disintegration
- Level detection, flow meters

Other:

- Sonar and other echo-location
- Bacterial disinfection via cavitation
- Parts cleaning (jewelry, medical equipment)
- Algae control (last but not least!)

Ultrasound Speed and Wavelength

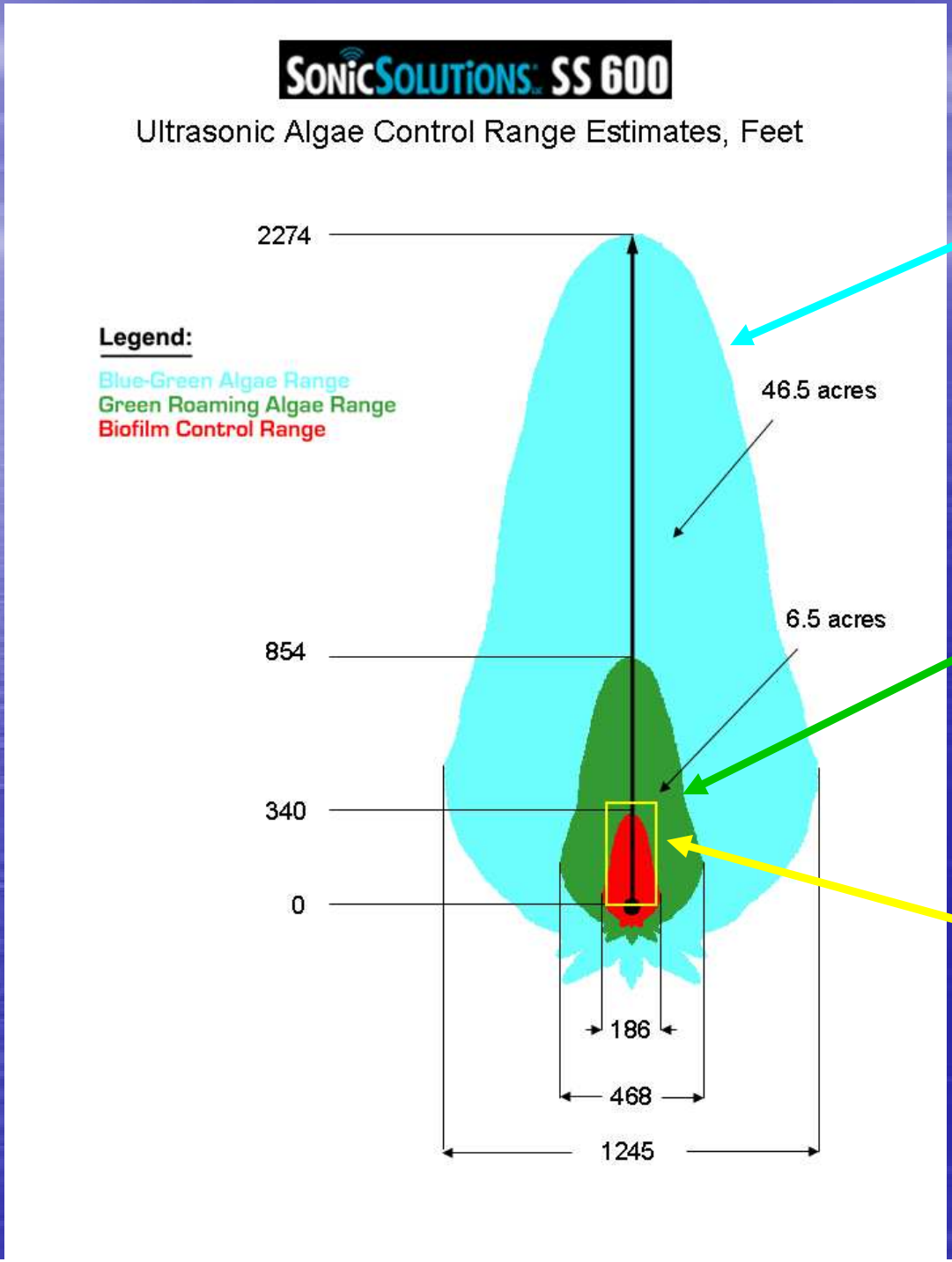
Sound travels at 4710 feet/sec or roughly 0.9 miles/sec in fresh water, over 4 times faster than in air. That's over 3200 miles per hour!

Speed/frequency = wavelength

4710/24000 Hz= 0.20 feet or 2.4 inches

4710/64000 Hz= 0.07 feet or 0.9 inches

Ultrasound Transducer Output Pattern – Largest Unit



Blue-Green Algae (cyanobacteria) Kill Range

Green Algae Kill Range

Size of a Football Field with End Zones

Before and After Results Using Sonic Solutions Ultrasound

BEFORE

using SonicSolutions® Algae Control

AFTER

using SonicSolutions® Algae Control

Before and After Results Using Sonic Solutions Ultrasound

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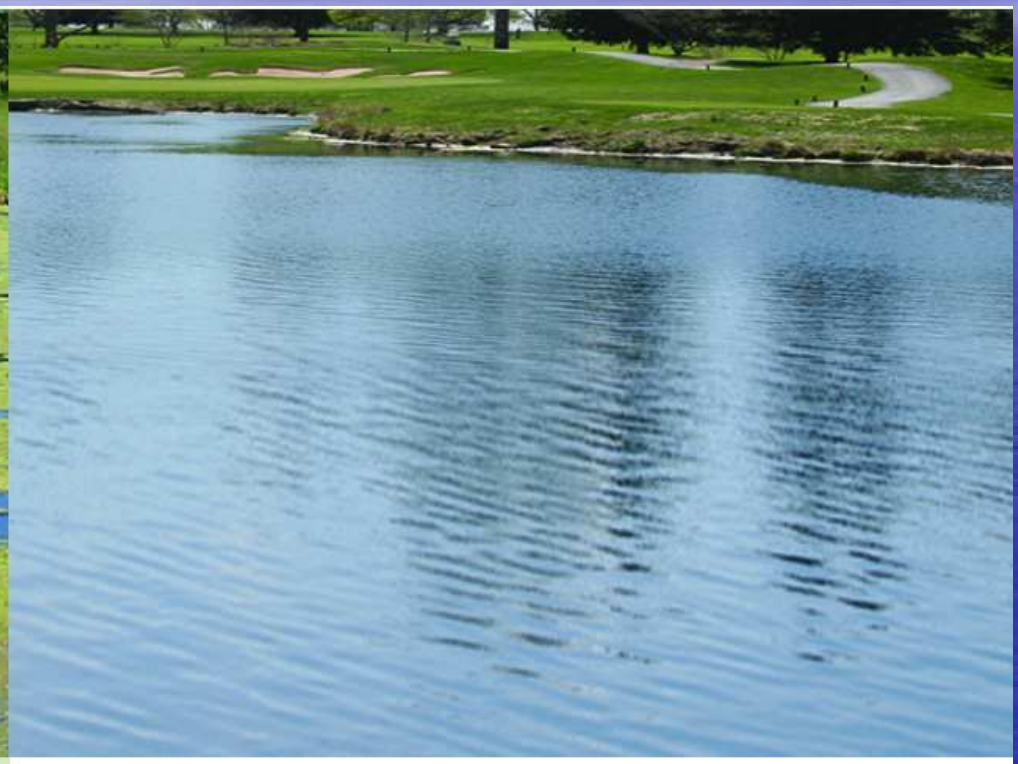


AFTER

using SonicSolutions® Algae Control

Before and After Results Using Sonic Solutions Ultrasound

BEFORE

using SonicSolutions® Algae Control

AFTER

using SonicSolutions® Algae Control

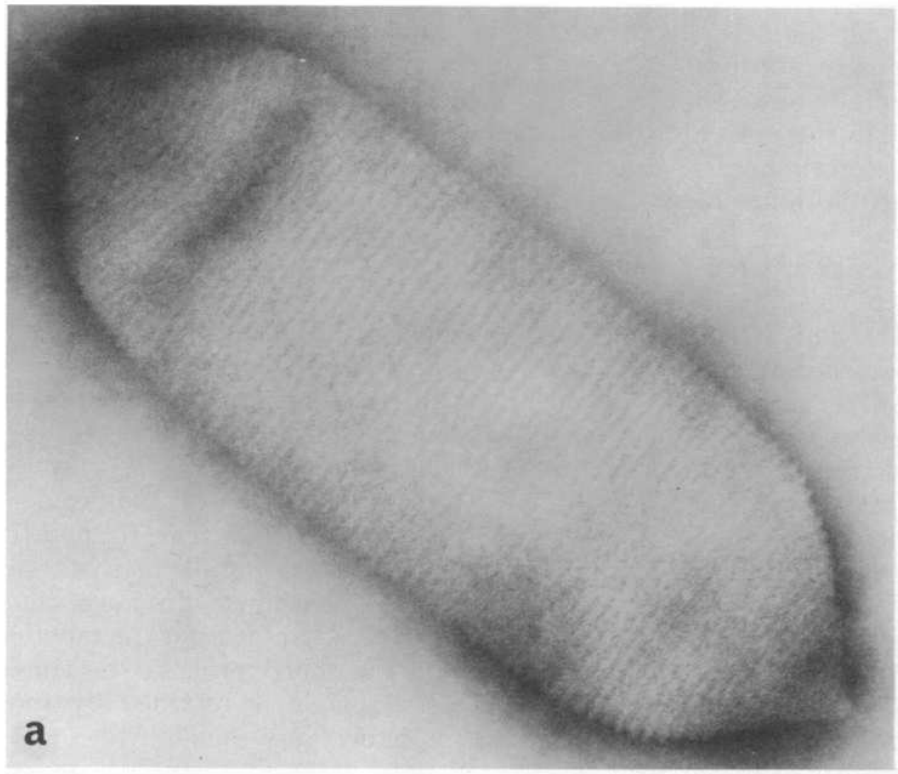
Algae Biological Parts Make Them Susceptible To Critical Resonance Vibration

Blue-green Algae (cyanobacteria) Gas Vacuole:

A cellular organelle with many tiny cylindrical vesicles about 75 x 300 nm in size, often in clusters. The wall of the gas vacuole, which is permeable to gases but not to water and is about 2 nm thick. Gas vacuoles are found mainly in planktonic cyanobacteria and their primary purpose is to make them buoyant. Some fungi and archaea bacteria have gas vesicles and will be affected.

http://www.biology-online.org/

Algae Biological Parts Make Them Susceptible To Critical Resonance Vibration



Intact gas vesicle of Anabaena flos-aquae negatively stained with phospho-tung-state showing corrugated profile of the ribbed structure x300000.

Ref. Fig. 12 Structure and function of gas vacuoles. A E Walsby, 1972.

Gas Vesicle:

Rigid hollow cylindrical structures with conical ends made of proteins. As blue-green algae create carbohydrate mass or better termed ballast during sunlight hours, they will gain enough weight to be heavier than water and sink. This allows them to find necessary nutrients near the bottom or at lower depths. As the carbohydrate ballast is consumed, they slowly rise to the surface.

Blue-Green Algae Can Have Thousands of Gas Vesicles

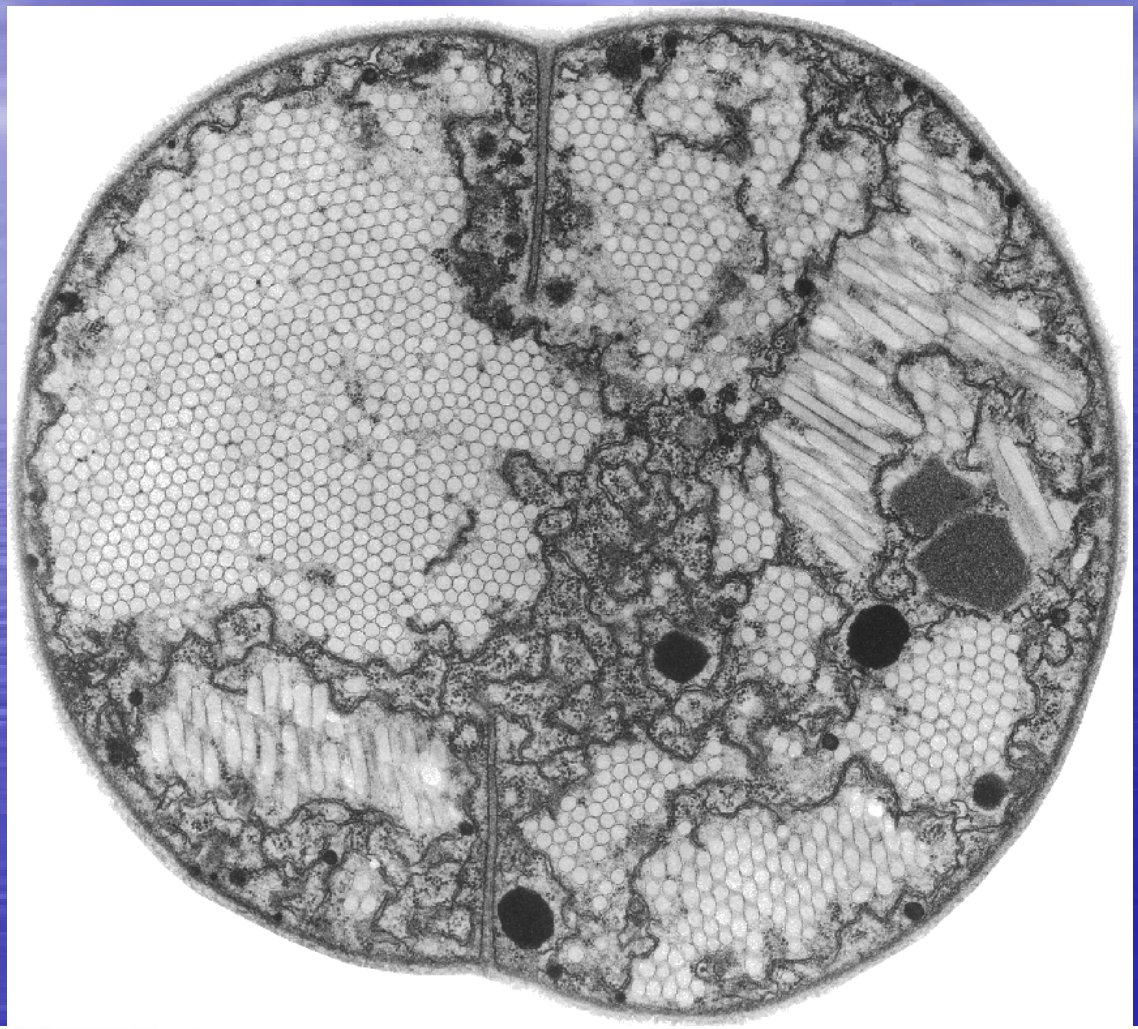
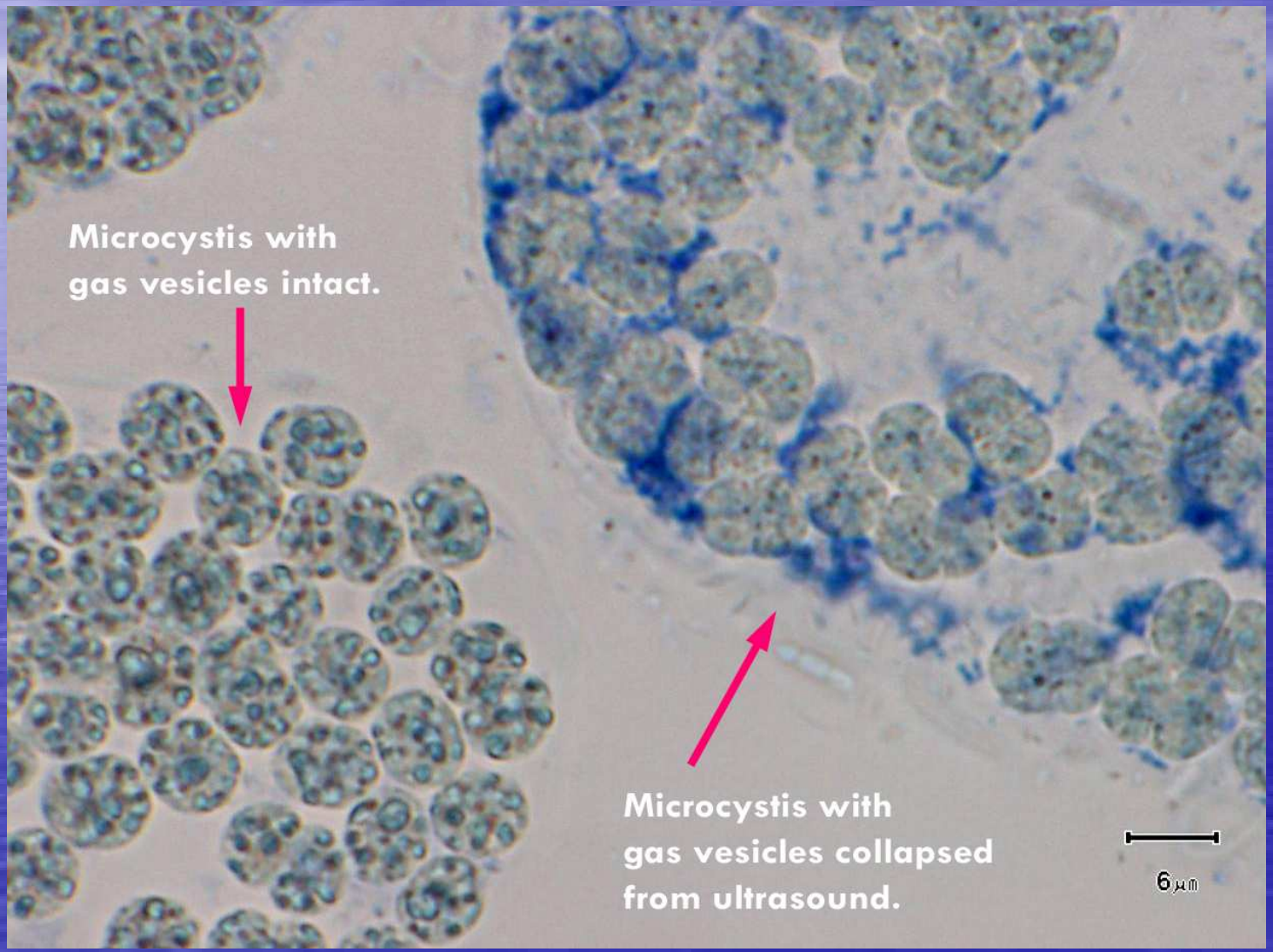


FIG. 1. Transverse section of a dividing cell of the cyanobacterium *Microcystis sp.* showing hexagonal stacking of the cylindrical gas vesicles. (Micrograph by H. S. Pankratz.) Magnification, x31,500.

Ref: “Gas Vesicles”, Anthony E. Walsby, Microbiological Reviews, March, 1994

Blue-Green Algae With Ultrasonically Damaged Gas Vesicles – Before/After



Other Targets of Ultrasound Resonance Vibration

Contractile vacuoles are osmoregulatory organelles on the algae outer sheath surface and allow water and nutrients to flow into and out of the cell through specialized membrane transporters called aquaporins.

They are connected to the plasmalemma or inner cell wall that lies beneath the outer sheath. The ultrasound causes the plasmalemma to detach from the outer wall and the contractile vacuole. When this occurs, the internal cell begins to shrink as it can no longer control its internal pressure, receive nutrients, expel waste, or protect itself from external bacterial attack.

Targets of Ultrasound Resonance Vibration

How this works:

Vacuoles take up water through specialized membrane transporters called aquaporins. They control the internal pressure needed for cell growth by controlling rates of water and ion movement across the algae cell walls.

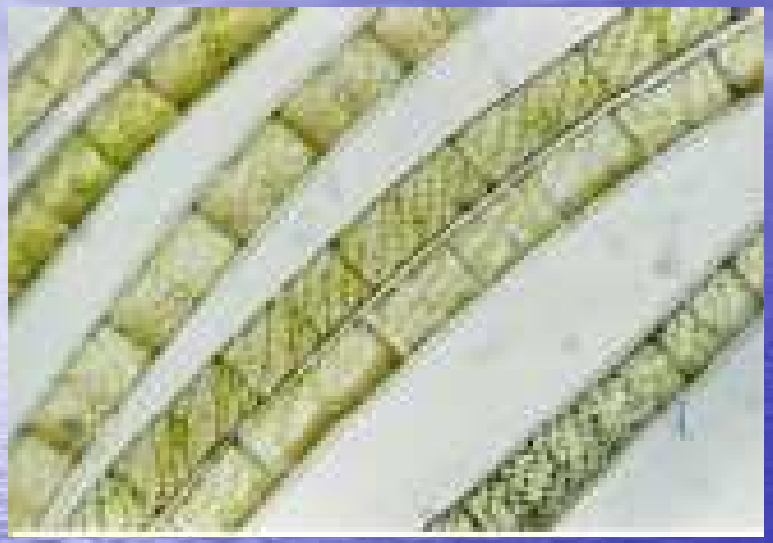
In fresh water algae and fungi lacking cell walls, **contractile vacuoles** fill with excess water from the algae cell and expel it from the cell. Ultrasonic resonance vibration damages these specialized membranes causing loss of critical life functions and ultimately death.

Effects Of Ultrasound On Algae

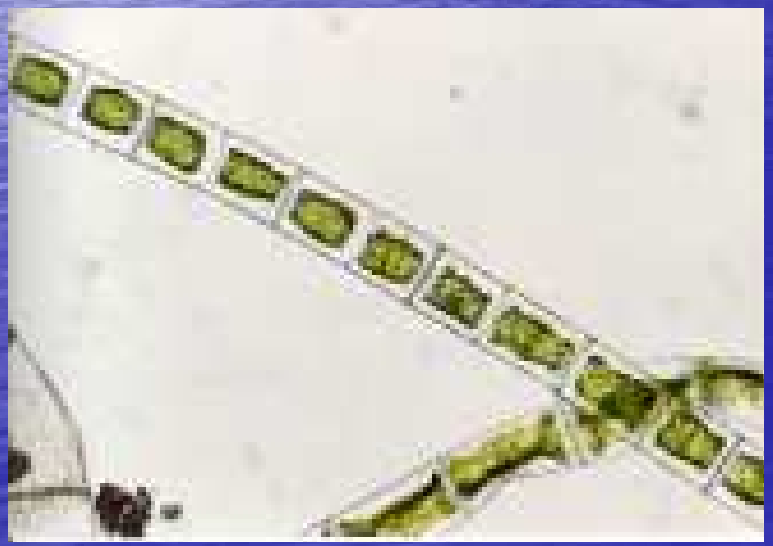
The following pictures of *Spirogyra* were taken over a three week period from a tank experiment done in controlled glasshouse conditions. The mode of action appears to be by disruption of the connections between the plasmalemma and the algal cell walls causing loss of membrane integrity, probable leakage of cytoplasm and a collapse of the cell into a dense brown mass. The cells remain buoyant for at least 4-5 weeks after exposure, although they are no longer viable.

Effects Of Ultrasound On Algae

Centre for Aquatic Plant Management, UK Work
Commissioned by Sonic Solutions, LLC



The picture on the left shows healthy *Spirogyra*, with cells full of cytoplasm, and the characteristic spiraling chloroplasts. The algae was sourced from a tank at the CAPM in Sonning and had been healthy for at least 5 years.



This picture was taken after only 7 days exposure to ultrasound. Already the plasmalemma is coming away from the cell wall, and the cells have shrunk. There is increased granulation of the cytoplasm, indicating loss of chloroplast structure, and loss of connectivity with other cells and the external environment.

Effects Of Ultrasound On Algae

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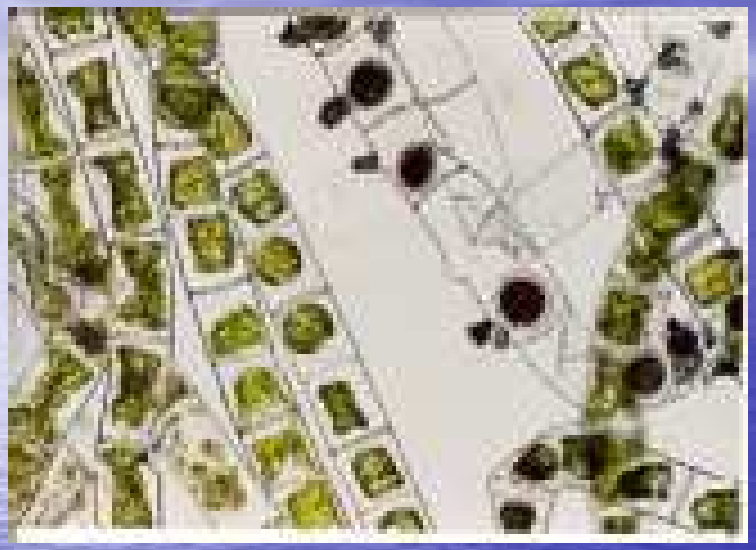
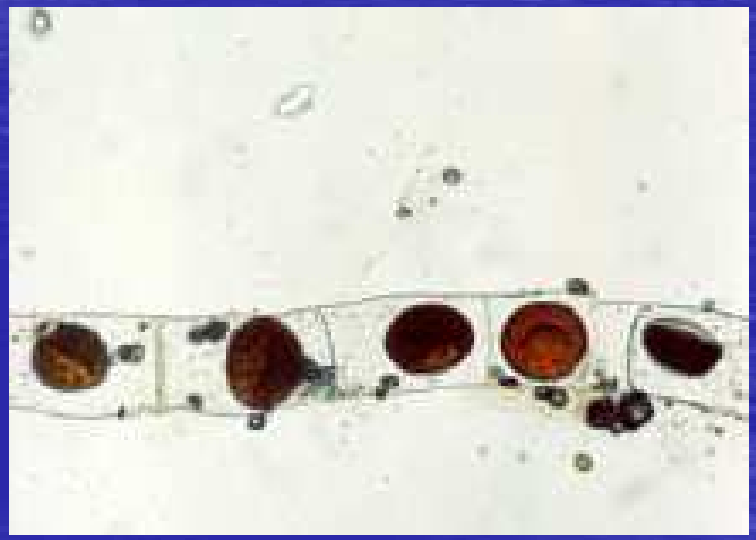


This picture was taken after 14 days exposure. The cells have continued to shrink, with some forming denser circular brown agglomerations in the center of the cell. There is some evidence of cytoplasm leakage from the cells, indicating further damage to the cell walls.

The picture on the right was taken after 21 days, and shows complete breakdown of cell structure.



Ultrasound Side Benefit: Biofilm Impact

Biofilm formation, made primarily from initial bacterial layers and then colonized by algae and other organisms, is greatly reduced in the presence of ultrasonic waves.

In cooling towers, interruption of the biofilm colony by ultrasound has been shown to reduce Legionella count.

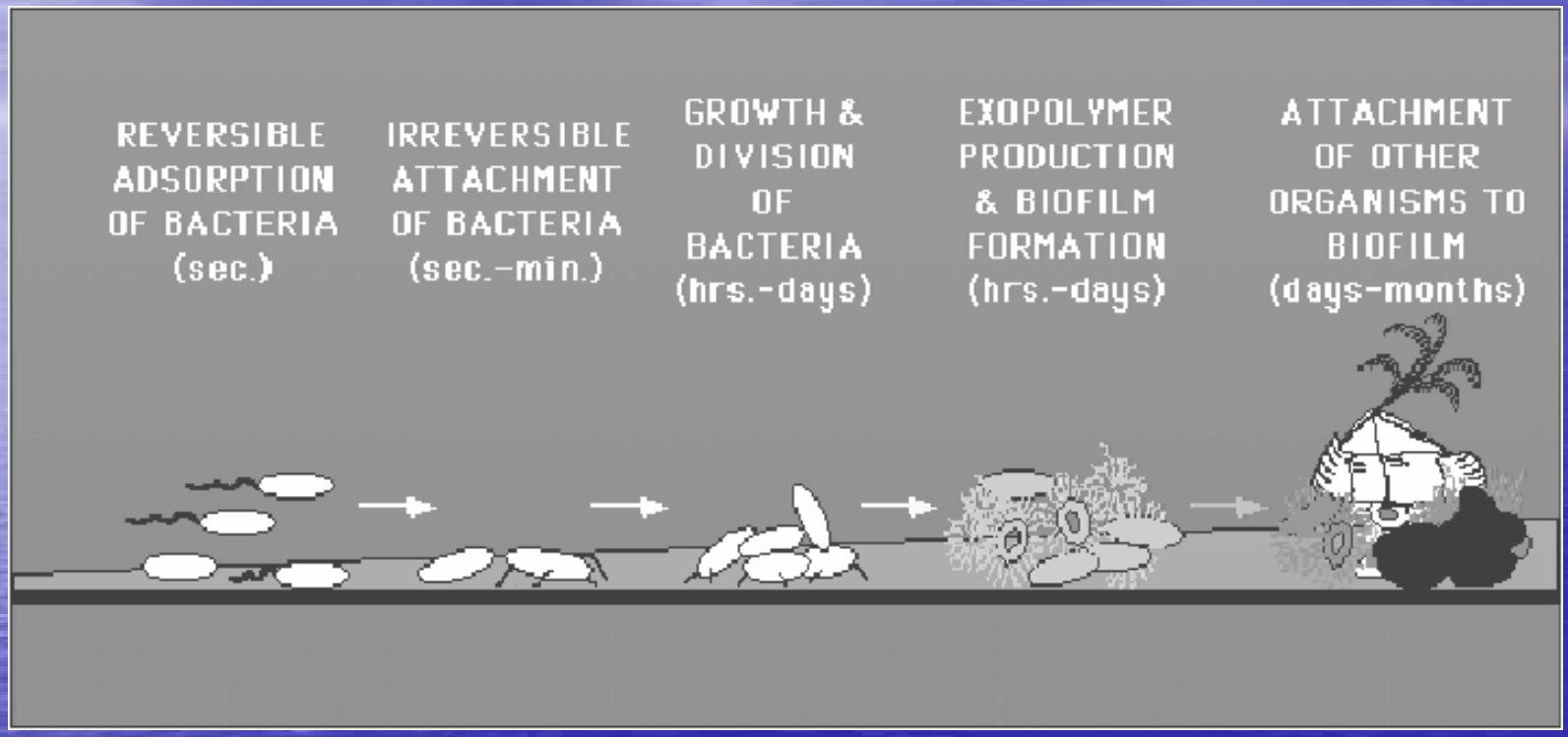
Numerous water facilities have reported a stark drop in biofilm formation after ultrasound is introduced.

Ultrasound Side Benefit: Biofilm Impact

How does this work?

The base layer of biofilm is comprised of anaerobic bacteria. These bacteria spread in water systems by becoming oxygen tolerant for a short period. In turbulent water, studies have shown that these types of bacteria withdraw their pili (small filament used for attachment) and do not excrete polysaccharide glues that they use to attach to surfaces, so they do not form colonies in turbulent water. The ultrasonic waves give them a sense that the water is turbulent, though it is not.

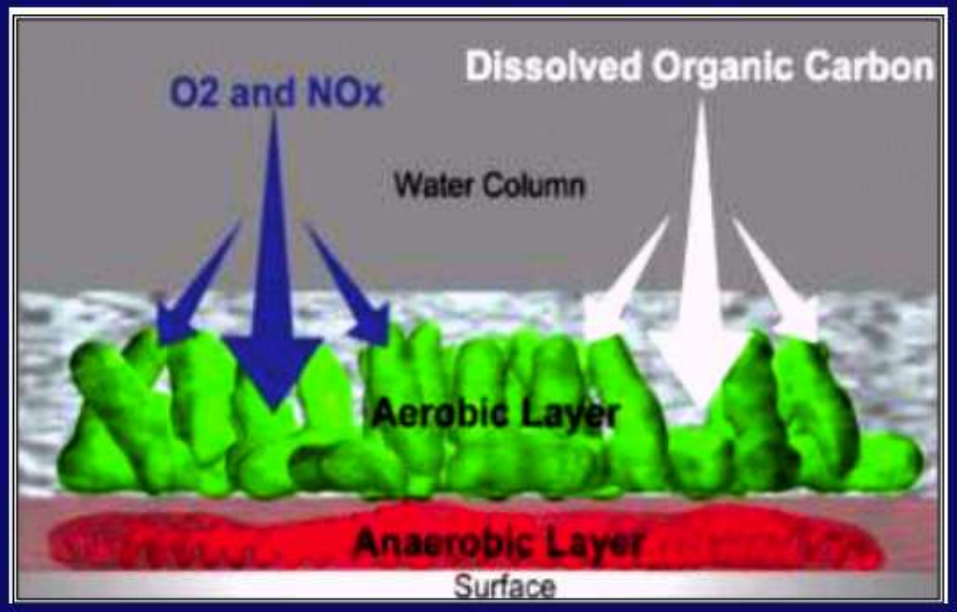
Ultrasound Side Benefit: Biofilm Impact



Ultrasound keeps the bacteria in the reversible absorption stage by producing a sensation of turbulence.

Ultrasound Side Benefit: Biofilm Impact

MICROBIAL BIOFILMS



STRUCTURAL HETEROGENIETY

Biofilm appears to be homogeneous accumulation of slime to the naked eye. However, when viewed at the microscopic level, biofilm is composed of bacterial micro colonies surrounded by exo-polysaccharide separated by water channels and is a complex ecosystem formed by anaerobic bacteria, microaerophilic bacteria and aerobic bacteria

Ultrasound Side Benefit: Biofilm Impact

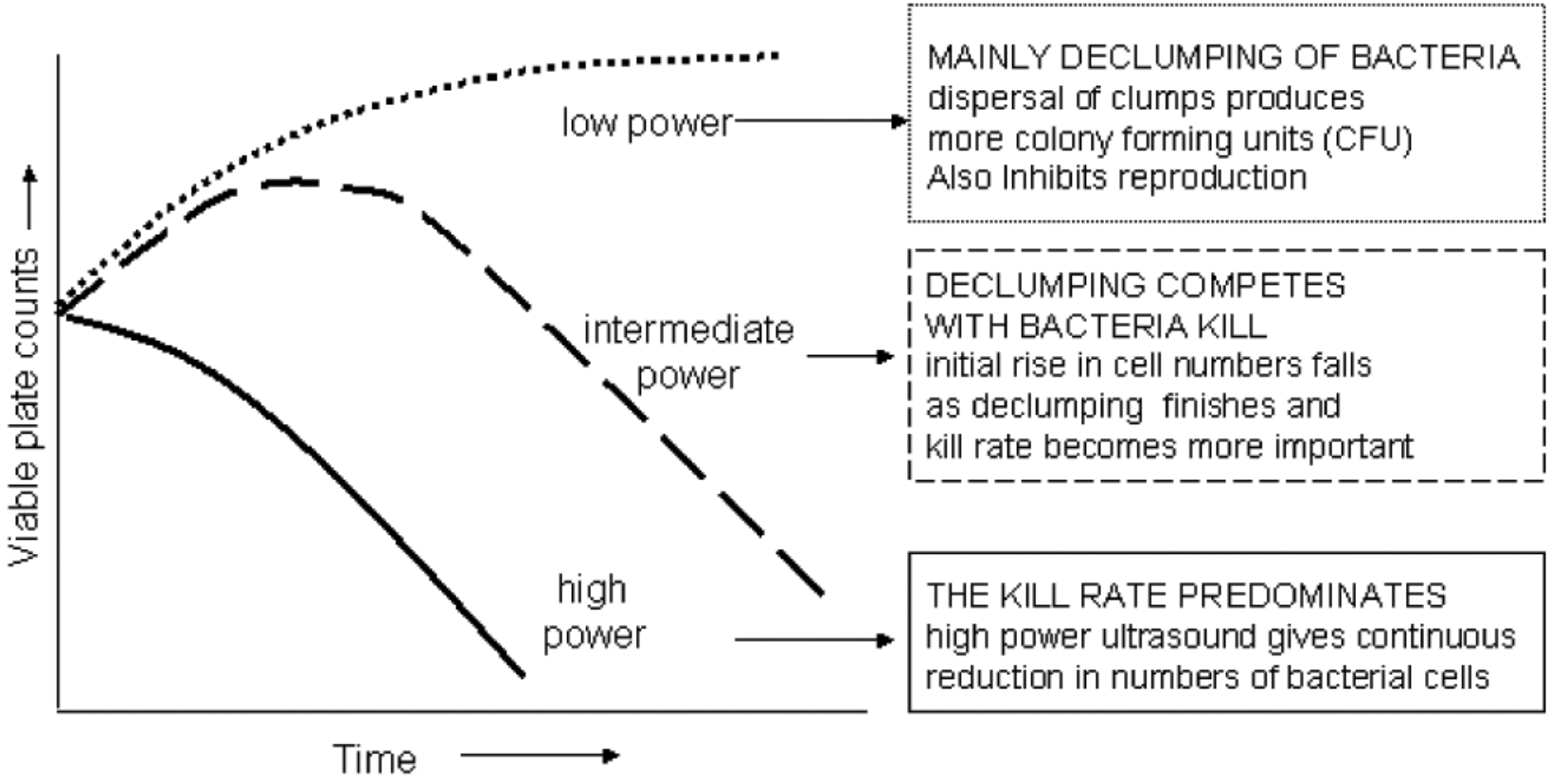


Figure 2: The effects of sonication alone on the survival of bacteria in water.

USES OF ULTRASOUND IN THE BIOLOGICAL DECONTAMINATION OF WATER
Sonochemistry Centre, School of Science and the Environment, Coventry University, T. J. Mason

Ultrasound Side Benefit: Biofilm Impact

Will it remove existing biofilm?

Typically, existing biofilm will brown out on the edges, but will not always completely go away.

Again, mother nature has provided bacteria a means of "quorum sensing", so an existing colony will give out a chemical that tells other bacteria of like genetics, that a compatible colony exists. Despite the ultrasonic vibrations, new bacteria will attach.

For best results, starting with a mechanically or chemically cleaned surface will prevent reattachment of strongly attached biofilm.

Ultrasound Side Benefit: Biofilm Impact

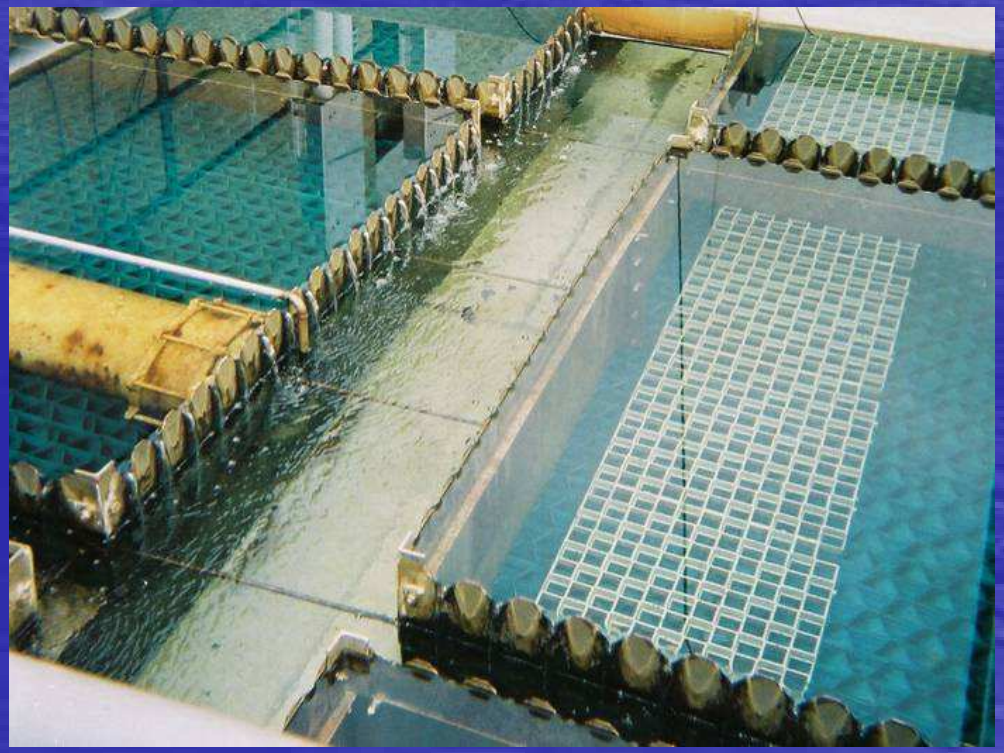
Before

Their Jan-08 THM level measured 34.4 ppb, well under the specified regulated threshold of 80 ppb. The HAAS level is 22 ppb compared to the 60 ppb maximum level.

Union, SC Potable Water Plant

Cleaning cycles increased from two to six weeks after introduction of Ultrasound.

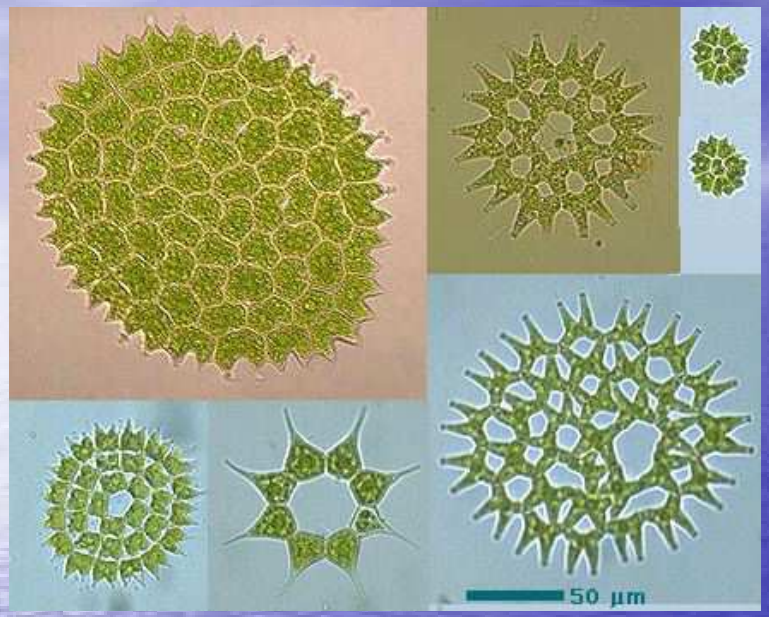
After



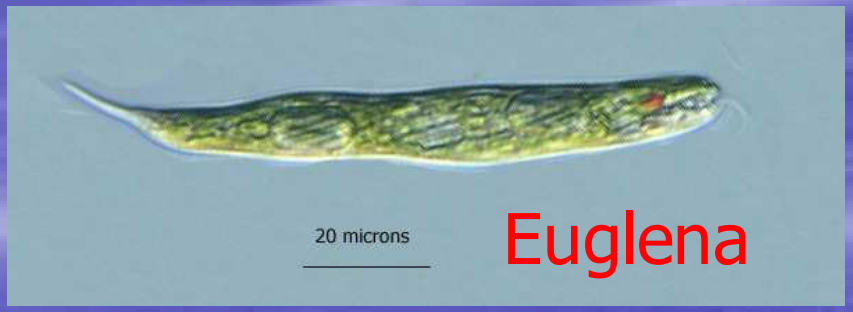
Macrophytic Algae Not Controlled With Ultrasound

If it looks like a plant, it is unlikely that ultrasound will harm it.

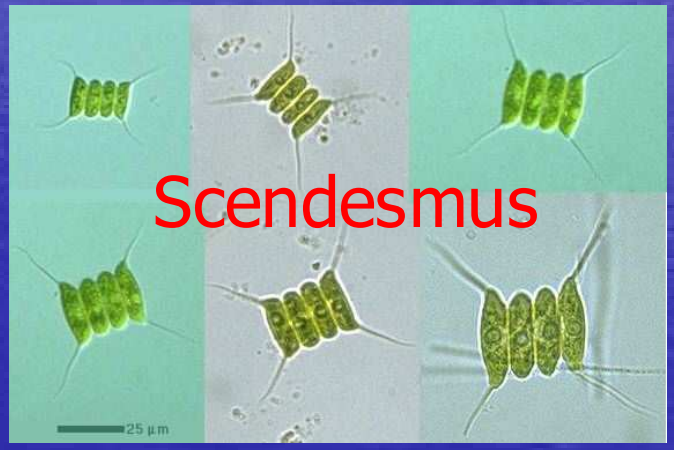
Types of Algae Not Controlled With Ultrasound



Pediastrum Types



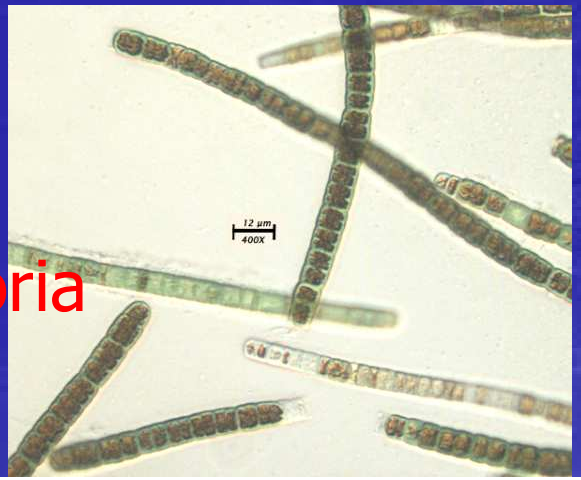
Euglena



Scendesmus

Cylindrospermopsis Raciborskii

Oscillatoria



Advantages of Ultrasonic Algae Control

- ✓ 100% environmentally friendly.
- ✓ No generation of by-products.
- ✓ No genetic mutation of survivors.
- ✓ Simple to install.
- ✓ Very little maintenance is required.
- ✓ No chemicals or additives needed.
- ✓ Very low energy consumption.
- ✓ Relatively inexpensive to purchase.
- ✓ Large water bodies are no problem.
- ✓ Wall biofilm where significant quantities of bacteria are produced can be significantly reduced or eliminated.

Disadvantages of Ultrasonic Algae Control

- ✓ Macrophytic or plantlike algae are more difficult to eliminate or are unaffected.
- ✓ Thick plants or these plantlike macrophytic algae structures can prevent ultrasound vibration to reach other parts of the water to be treated.
- ✓ A "line of sight" to the algae must be available for the transducer output to be effective.
- ✓ A few algae types will not be affected by ultrasound (euglenoids, oscillatoria, scendesmus, macrophytic, and some colonical types like pediastrum are resistant).
- ✓ Patience is required as weeks are sometimes needed for full effectiveness.

Summary:

- Ultrasonic algae control is now a viable and cost effective way to control most nuisance algae types.
- This technology offers an environmentally friendly approach, eliminating many chemicals and chemical handling issues.
- Other than a few fungi that have gas vesicles and certain bacteria that will stop propagating in the near field zone, the ultrasound technology using resonance frequency has not been shown to affect life forms other than algae.