Big noise in sludge treatment

Fluidsonics - the application of ultrasound to water systems - offers great potential for dealing with wastewater sludges, with high-energy systems showing promise in biological process enhancement, sludge disinfection, and dewatering.

The water industry has used low intensity ultrasound for over 20 years. Applications include flow and level measurement, using ultrasound meters that are now generally highly reliable and as accurate as electromagnetic devices. Some forms of non-destructive testing of materials also exploit low energy ultrasound. However, high power ultrasound is still rare in the water industry.

Sound is longitudinal waves of alternating negative and positive pressures and ultrasound is the term describing frequencies greater than 20MHz, beyond the range of human hearing.

High-power ultrasound is normally generated by a transducer, and delivered into a fluid via a horn or probe. Electromechanical transducers can be magnetostrictive or piezoelectric, and electromagnetic systems are the most versatile and widely used, despite their relatively high cost. However, ultrasonic transducers can also be gas driven, using the same principle as a dog whistle, or liquid driven.

In high-powered applications of ultrasound to liquids, the cycles of rarefaction and compression can cause the growth and collapse of micro-bubbles of gas. Understanding and quantifying this 'cavitation' effect is said to be vital in determining the feasibility of high-power ultrasound in industry. Cavitation occurs only if the ultrasonic energy applied exceeds the molecular attractive forces. In water, cavitation will generally occur at energy levels greater than $1W/cm^2$. Above the cavitation threshold, bubble implosions will produce hot spots in the liquid, lasting only microseconds. These hot spots can release sufficient energy to drive various chemical reactions.

Apart from the amount of sonic energy transmitted through the liquid, a number of other factors influence cavitation. These include the medium's temperature, its viscosity and the surface tension, as well as duration and frequency of the sound. Cavitation produced by high ultrasonic intensity is 'transient', while it is 'stable' at relatively low intensities.

With transient cavitation, vapour-filled bubbles can treble in radius over one to three acoustic cycles. On implosion, the bubbles produce localised pressures exceeding 1,000 bar and temperatures of over 5000 deg. C, and they also form nuclei for new bubbles. The implosion energy is sufficient to stimulate the production of chemical free radicals, and the shock waves can be used to enhance reactions.

In contrast, stable cavitation is associated with slowly growing bubbles, which enable heat and gas to transfer across their surfaces. When stable bubbles collapse, their gas content cushions the implosion and reduces the reaction violence. Before collapsing, bubbles grow to a critical size determined by the frequency of the ultrasound. At a frequency of 20kHz, the critical bubble diameter is likely to be 170 microns.

Ultrasonic energy is attenuated by scattering, internal adsorption and, to a lesser extent, the attenuation coefficient of the fluid. In fluids with particles significantly smaller than the ultrasonic wavelength, such as sewage sludges, the scattering effect is minimal but absorption is high. Cavitation bubbles provide shielding against sound waves, reducing the effect further.

Laboratory and pilot scale work has demonstrated the value of ultrasound in wastewater treatment. However, more work is needed to address issues such as securing delivery of uniform ultrasonic intensities, improving energy transfer efficiencies through digital amplifiers, ensuring high reliability and operational consistency of equipment, and improving transducer lifetime expectancies: piezoelectric transducers now last only two or three years, while magnetostrictive devices can last 10 years.

Exploiting high power ultrasound requires detailed knowledge of parameters, such as intensity and energy density, and of cavitation events in the liquid medium. The UK's National Physical Laboratory is now developing reliable methods to measure ultrasonic intensities and to monitor cavitation in fluids. Many existing methods, using underwater microphones, thermal sensors, optical techniques and chemical dosimetry provide only average values, and are not necessarily adequate for optimising processes or for scaling up for industrial applications.

In development work, the trend appears to be towards building pilot-scale plants to address specific issues. Ultrasonic baths are effective for small applications, but they are unlikely to be suitable for full-scale processing plants because of difficulties in reproducing attenuation patterns and their low power intensities. Ultrasonic probes or horns are well suited for use in the water industry, since they deliver focused, highly intense streams of ultrasound. However, the horn tips tend to wear out and the range of influence is reduced because of scattering and attenuation. To deal with this, a pumped loop design for ultrasonic plant has been proposed. This would be easy to retrofit and, being modular, would lend itself to scale-up. It also provides considerable control over the hydraulic retention time through the zone exposed to ultrasound.

A number of key design issues have been identified for ultrasonic applications in general. These include accuracy, especially where flows or liquid levels are being measured. Cost effectiveness, which is vital in process application, and reliability are also significant. High reliability is particularly important in safety-critical applications of ultrasound, such as disinfection.

A patent search conducted a few years ago found almost 3000 references including the term ultrasound. This high level of patent activity reflects the interest in ultrasonic-based applications, and it is likely that significant developments in sludge treatment and beyond are on the way. ■

This article summarises the paper 'High power ultrasonic applications in sludge processing' by Dr P B Clark, WS Atkins Water, Epsom, UK, and presented at Asian Waterqual 97, the 6th IAWQ Asia-Pacific Regional Conference, 20-23 May 1997, Seoul, Korea.

Great potential for sludge processing

Sludge thickening

Ultrasound can influence intermolecular forces that encourage particle agglomeration and, therefore, sludge thickening. Ultrasonic intensity should, for optimal effect, be below the cavitation threshold, and the sludge may need prior degassing to minimise the number of bubbles acting as cavitation nuclei.

If an ultrasonic standing wave is created, particles will move towards fixed locations and fuse together. Ultrasound has been shown to improve sludge coagulation significantly, reducing by half the polyelectrolyte dose required. Ultrasound can also aid sludge thickening by weakening electrostatic charges between molecules or rupturing bacterial cells. Once internal solutions are released from ruptured cells, the sludge can be pressed more effectively with filter presses. Pilot-scale versions of the Demicell process at a number of German wastewater treatment plants use this principle. Also the Battelle Institute, Ohio, USA, has assessed whether combining ultrasound with electrical energy enhances the performance of belt presses in the patented Electro-Acoustic Dewatering process. Developmental work continues.

Better biological processes

Low-intensity ultrasound can improve biological processes by enzyme enhancement. Laboratory experiments using very high frequencies have shown ultrasound to intensify the growth and enzymatic activity of activated sludge micro-organisms. At the other end of the scale, low frequencies can disperse sludge clumps, reducing effective particle size, and increase the surface area for biological activity.

To destroy cells with high-intensity ultrasonics, cavitation must occur within one or two microns of the bacterial cell, and for best results sludge thicknesses should be no more than 3%TS. Above this figure, significant attenuation of the ultrasonic intensity tends to occur. Frequencies of 20kHz are usually applied, ensuring maximum power input and cavitation.

Research in the 1960s demonstrated that sludge digestion could be significantly increased through ultrasonic applications. Increases in BOD and COD, probably caused by releases of intracellular organics, were noted, along with dramatic decreases in bacterial numbers. However, the settleability of ultrasonically processed sludge was less than of untreated samples.

Foam remover

Ultrasonic sound can disperse surface foam, and an industrial scale device has successfully operated in the beverage canning industry.

Degassing

Degassing is a relatively simple application, developed both in the glass and water industries. The UK company Yorkshire Water appears to have demonstrated mechanisms for degassing post-digestion sludges in laboratory tests. Dissolved gases in the fluid act as nuclei for stable cavitation. As bubbles, grow they float to the surface. If the gas is particularly soluble, it may redissolve after bubble implosion.

Filtration enhancer

Conventional filtration tends to be inefficient when the particulate distribution is small. Filtration and centrifugation remove only the bulk water. But ultrasound is thought to help release capillary and bonded water as well. Also, vibrations from ultrasound may help to suspend particles away from the filter face, improving its efficiency. Work is in hand further to improve filtration by combining ultrasound with electrical fields.

Bacteria killer

Cavitation can aid wastewater disinfection by destroying bacteria or by generating free radicals to rupture their cell walls. Rupturing walls has been shown to remove both cryptosporidium oocysts and giardia organisms.