

Improved wastewater disinfection by ultrasonic pre-treatment

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Wastewater disinfection has been getting more significance within the last years and ultraviolet irradiation has turned out to be an effective and cost efficient alternative to chlorine disinfection. However, the presence of particulate matter in water samples is a major obstacle in UV disinfection as the UV light is scattered, and bacteria are shaded by or incorporated into flocs. In order to achieve required reduction of microbial counts (e.g. total coliforms, fecal coliforms, *E. coli* and streptococci) necessary UV doses have to be raised considerably as a function of the concentration of total suspended solids.

Ultrasound (US), operated at low frequencies, is an effective means for disintegration of bacterial cells: First at low ultrasound doses bacteria flocs can be deagglomerated by mechanical shear stresses. If the US dose is increased ultrasound cavitation impacts on the cell walls such that they are broken. This effect is lethal to the microorganisms.

The objective of our work is to evaluate the scientific and economic potential of US application as pre-treatment step in combination with UV to optimise the disinfection process of wastewaters.

In our lab-scale experiments a horn sonotrode operated at 20 kHz was used to sonicate wastewater samples taken from the effluent of a municipal treatment plant. The ultrasound intensity was varied between 1.7 and 60.8 W/cm², power density ranged from 10 to 400 Watts per litre sample volume. Subsequent UV treatment was realised by a low-pressure mercury arc lamp.

Ultrasound application of 20 s at low density of 30W/L changed the particle size distribution (PSD) of the samples. The mean particle diameter dropped from 70 µm to 11 µm. An increase of the US intensity (80, 220, 310 W/L) then had only marginal effects. The resulting mean particle diameter was 9, 7 and 6 µm, respectively. Generally it is assumed that bioparticles bigger than 50 µm are difficult to disinfect by UV. We observed that the relevant particle size range >50 µm of the samples was reduced by at least three-quarters by low ultrasound doses for samples taken from the primary clarifier. As expected, these changes in PSD notably effect the disinfection efficiency of UV. Whereas UV treatment of secondary clarifier's effluents alone led to a reduction of fecal coliforms by 2.5 log units, pre-treatment by sonication (only five seconds at densities of 50 and 310 W/L) clearly enhanced the disinfection efficiency: Reductions of CFU concentration now ranged between 3.3 and 3.7 log. units. We noticed an influence of the bacteria's morphology on the disinfection efficiency of the combined process (US plus UV). Gram-positive streptococci seem less vulnerable to ultrasound exposure than thinner-walled gram-negative bacteria like the entire group of coliforms.

The application of an additional ultrasound step might be useful also in terms of cost-effectiveness. 30 seconds of UV treatment were required to reduce the number of fecal coliforms by 3.7 log. units, 5 seconds of ultrasonic followed by 5 seconds of UV irradiation had the same result - and energy consumption was only 43%.

The observed effects could not always be explained by analysis of physical parameters (changes in PSD and turbidity) alone. Further investigations have to be carried out in order

to better understand the involved phenomena. Moreover, we want to look into the effect of ultrasound on bacterial re-growth, the weak point of UV disinfection.

Introduction

At present, it is not prescribed legally in Europe that sewage treatment plants' (STP) effluents have to meet microbiological criteria. Nevertheless, it is common sense that these effluents are disinfected when discharged into sensitive areas, as STPs' effluents represent a definite technical and legal "interface", that is easily provable. Therefore, in many European countries microbiological guidelines given in the EU Bathing Water Directive [1] are being adopted and applied to sewage treatment plants' effluents [2]. As counts of indicator organisms (such as fecal coliforms) are usually not reduced to tolerable levels within a conventional treatment process, an additional subsequent disinfection step is unavoidable.

Types of disinfection techniques are various: They include physical, chemical and natural/biological methods. Several studies have shown that the efficiency of disinfection methods is highly dependant on the sample's concentration of suspended solids (SS) [3],[4], due to the fact that SS can protect bacteria and viruses from being destroyed by disinfectants [5].

Especially ultraviolet (UV) irradiation has been getting more and more significance due to the absence of hazardous by-products. Nevertheless, UV applications are limited for samples with high concentrations of suspended matter [4]. Recent studies [6] have shown that large

particles (about 50 μm) are hard to penetrate so that the required UV demand is raised drastically. Therefore, it is common practice to install filters (e.g. rapid sand filters) to reduce particulate matter prior to the UV step. Rapid sand filters are expensive in construction and maintenance. They are well known in the treatment of potable water, but when it comes to treatment of wastewater they suffer from various drawbacks (e.g. clogging, algae growth, backwashing).

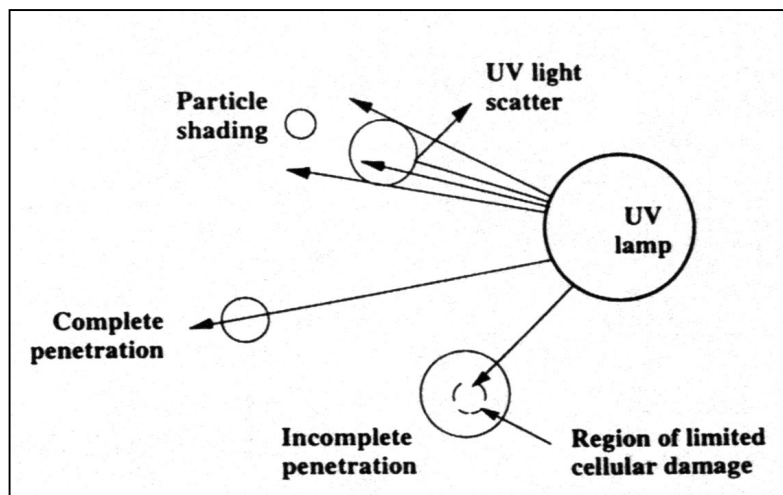


Figure 1: Effects of particles on UV disinfection

Another attempt to bring down the size of solids present in the water sample is the application of ultrasound. The aim of our experimental stage experiments presented here was to show that ultrasound provides an appropriate means to change the physical composition of the sample such as „big particles“ are transformed into smaller ones. Therefore, we tested a combination of ultrasonic pre-treatment and UV disinfection to find out whether changes in particle size distribution of wastewater samples facilitate a subsequent UV disinfection.

Equipment & Analytical Procedures

The experimental set-up is quite simple, as depicted in the accompanying schematic figure. In order to avoid sedimentation, a continuous set-up was chosen which also represents a technical system in a better way than a discontinuous system. 10 litres of treated municipal wastewater are stored in a glass bottle and mixed constantly by a magnetic stirrer. A peristaltic pump is used to convey the medium through the system: Firstly, it passes the ultrasound apparatus' flow chamber, secondly, it enters the ultraviolet device to be exposed to UV irradiation. Sampling outlets at various stages facilitate taking of samples after each individual step of treatment.

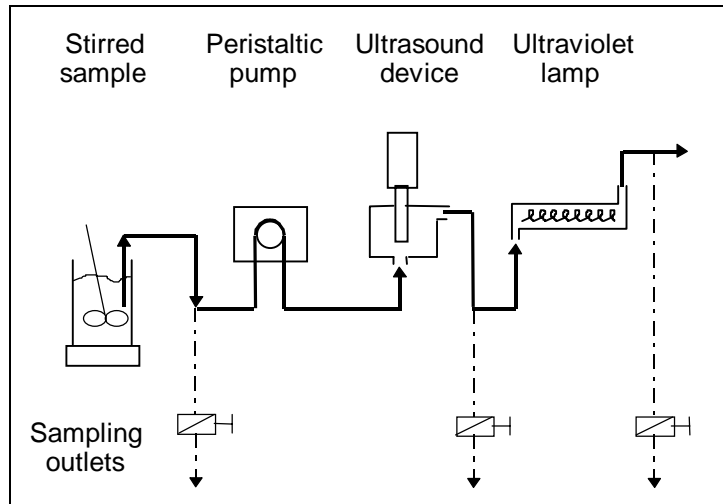


Figure 2: Flow scheme of the experimental set-up

The ultrasound device used was a “Branson Sonifier W-450“, a horn sonotrode equipped with a horn tip of 1.3 cm in diameter which is operated at 20 kHz. As strongest cavitation effects in terms of hydromechanical forces could be observed at low-frequency ultrasound application [7] this frequency was chosen.

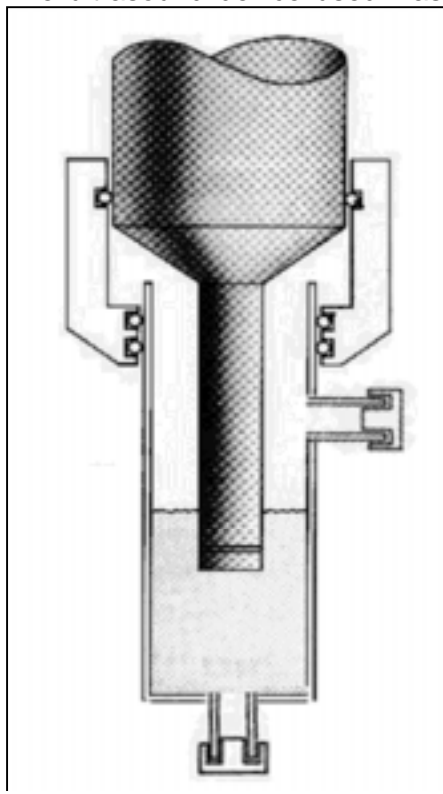


Figure 3: Horn sonotrode in a continuous flow chamber

Electrical power in the range of 41 to 154 Watts was applied, and calorimetric measurements exposed that intensities ranged from 1.7 to 60.8 W/cm², and densities from 10 to 400 W/L, respectively.

The low-pressure mercury arc lamp (manufacturer: “Pureflow Ultraviolet Inc.“, nominal length: 20 cm, diameter: 1.3 cm) is enclosed in a tubular floating chamber (volume: 300 ml). A surrounding thin layer of quartz glass shields the lamp from the sample that flows parallel to the orientation of the lamp. Its energy consumption is 14 Watts of which 3 Watts are emitted at 254 nm (37 μW/cm²@1m), the relevant wavelength for bacteria inactivation.

Particle size analysis was conducted with a Hiac Royco, Model 8000A (equipped with a sampler, model 3000A and a HRLD-150 sensor). In this automatic particle counter a laser diode functions as the illumination source and a photo diode serves as the detector. Particle counts and size distributions are calculated and displayed automatically.

The Spread Plate Technique (for high concentrations of microorganisms) and the Membrane Filtration Technique (for low levels of detectable microorganisms) have been applied

(according to the “Standard Methods for the Examination of Water and Wastewater“ [8]). For the enumeration of total germs, total coliforms, Escherichia coli, fecal coliforms and fecal streptococci, specific types of solid agar have been chosen. Results are presented as colony forming units (CFU) per 100ml.

Results & Discussion

Figure 4 demonstrates the capability of ultrasound application to eliminate the fraction of big particles: Samples (STP’s primary effluent) were treated for 20 seconds at various ultrasound densities. Initially, 63 % of the solids in the wastewater sample were characterised by a size bigger than 50 μm . After a sonication for 20 seconds at 30 W/L, this fraction just accounts for 5 % of the total counts. Increasing further ultrasound density (80 W/L, 220 W/L, 310 W/L), minor decreases in mean particle size occur. It stands out that low ultrasound energy (30 W/L) is already sufficient to provoke a clear change in particle composition. Further increased ultrasonic doses have only a marginal effect.

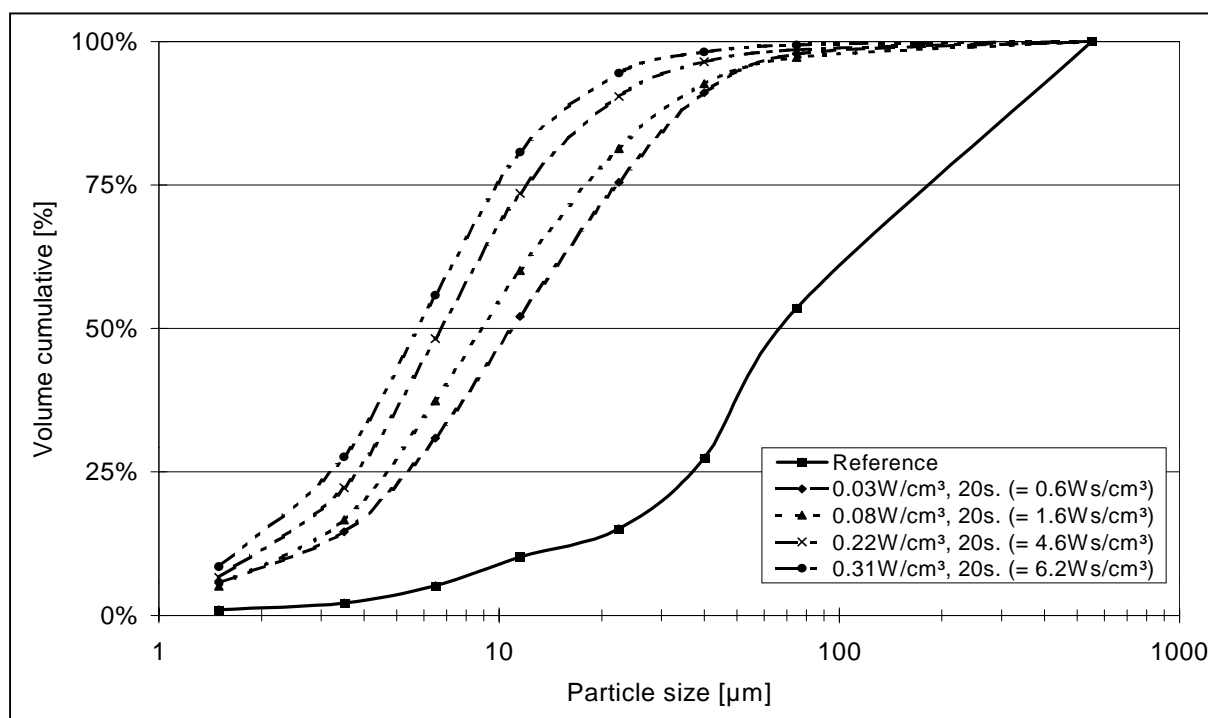


Figure 4: Effect of sonication on particle size distribution

The figure shows that ultrasonic treatment of wastewater has a similar effect like a sand filtration: Herwig et al. [9] reported that quartz sand filters are an appropriate means to eliminate fractions of particles bigger than 50 μm almost completely.

We observed in other tests that long-term sonication at maximum density (400 W/L) of up to 60 minutes leads to significant reductions of fecal coliforms (approx. 3 log. units). This is also in accordance with the findings of Hua et al. [10]. For economical aspects this method can not be considered an alternative to conventional disinfection: Energy input is almost factor 500 higher than for an UV treatment with the same reduction rates.

Therefore, our aim is to concentrate on short ultrasonic pre-treatment of wastewater samples prior to UV irradiation. This combination shows interesting results (Figure 5). STP’s secondary effluents (mean particle size: approx. 10 μm) have been irradiated by UV light for 5 seconds so that the content of fecal coliforms (FC) was reduced by 2.5 log. units. By prior

sonication of these samples for five seconds, disinfection efficiency could be improved markedly. At a low sonication level, disinfection rate could be improved by 0.8 log. units, for the higher ultrasound level efficiency could be enhanced by 1.2 orders of magnitude (compared with the not pre-treated sample).

This coincides with the results that were obtained from the particle size analysis. Our main interest is in destroying large particles as they protect bacteria from being disinfected, and Figure 5 shows that "critical particles" bigger than 50 μm could be reduced by 25 % and 60 % (volume related, dependant on the ultrasound dose applied) by ultrasonic pre-treatment, so that the subsequent UV treatment was far more fruitful.

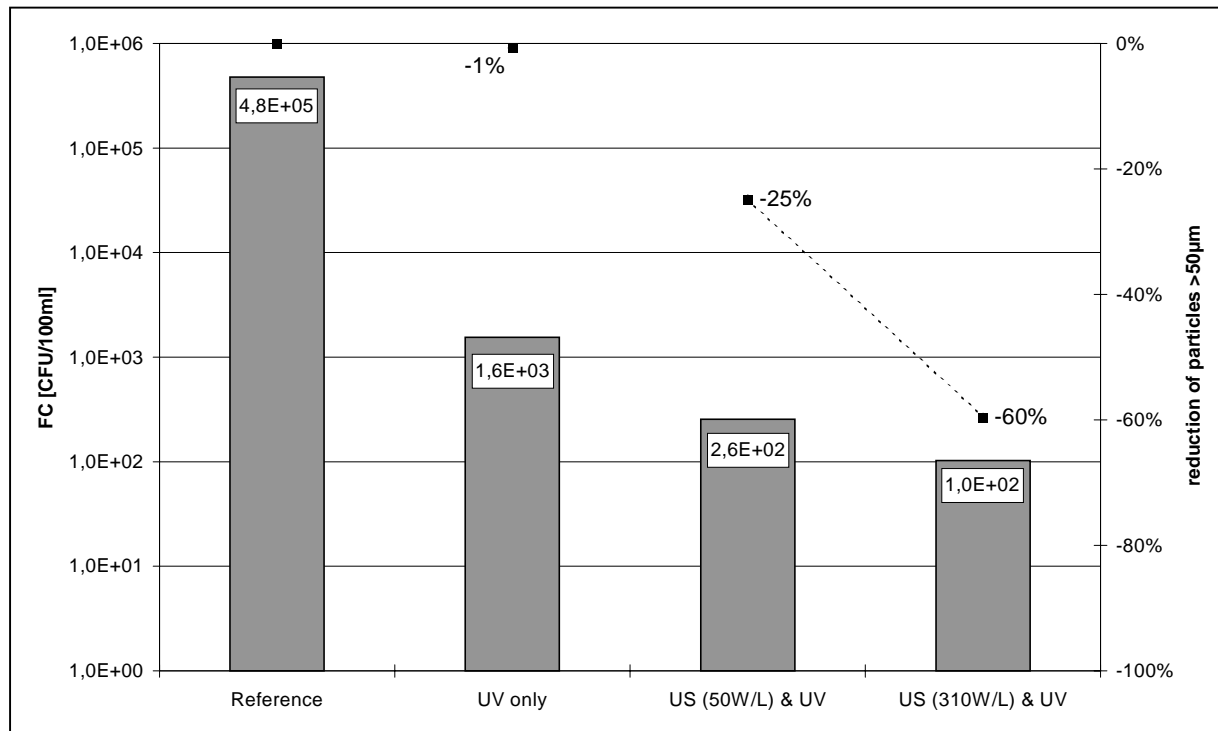


Figure 5: Effect of ultrasonic pre-treatment density (sonication time: 5 s.) on reduction of fecal coliforms and on number of particle counts >50 μm

The absence or inactivation of coliforms does not necessarily mean that the effluent was free of pathogens. Recent studies have revealed that the enterococci species of fecal streptococci are a better indicator of fecal pollution, because they show better correlation to human diseases and they survive longer in the water. Moreover, they are more resistant to environmental stress than commonly monitored coliforms [11].

For this reason we did not just focus on fecal coliforms, but also analysed the effect on the less vulnerable group of streptococci (see Figure 6): A sample with a high content of suspended matter (TSS= 4.88 mg/l, mean diameter: 60 μm) was treated with UV irradiation for 30 seconds. Ultrasonic pre-treatment at a density of 170 W/L for 10, 20, and 30 seconds, respectively, brought down mean particle size to 29, 17, and 12 μm , respectively, so that reduction of sample's mean particle size seems to be correlated directly with applied ultrasound dose such as higher doses provoke clearer reductions. For both microbiological parameters observed, the ultrasonic pre-treatment has a clear beneficial effect: Disinfection efficiency is by 1 to 3 orders of magnitude higher and the thicker-walled streptococcus species seems to be less vulnerable than E. colis.

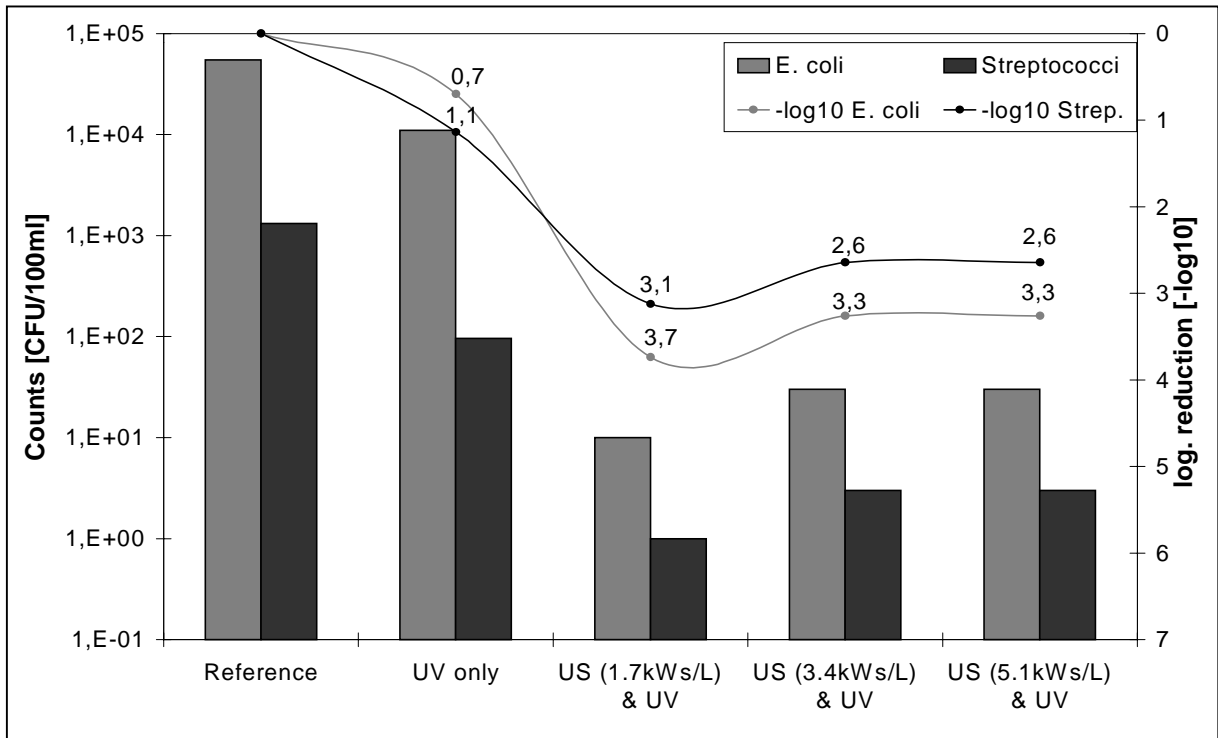


Figure 6: Ultrasonic pre-treatment (density: 170 W/L) for 10, 20, 30 s. and subsequent UV irradiation (UV dose: 1.5 kW/L): Effect on CFU

In order to demonstrate that the combination of a short ultrasonic and a subsequent ultraviolet treatment is even cost-efficient. the following Figure 7 demonstrates that this combination is very meaningful although ultrasound's specific energy consumption (80 W/L) is higher than the UV lamp's (50 W/L). Whereas 5 seconds of ultrasonic pre-treatment and 10 seconds of UV disinfection consume 900 Ws/L to reduce fecal coliforms to a level beneath the critical concentration of 100FC/100ml, an exclusive UV irradiation of as much as 30 seconds is not capable of achieving this goal and is even more "costly" as the consumed energy of 1500 Ws/L is about 66,7 % higher.

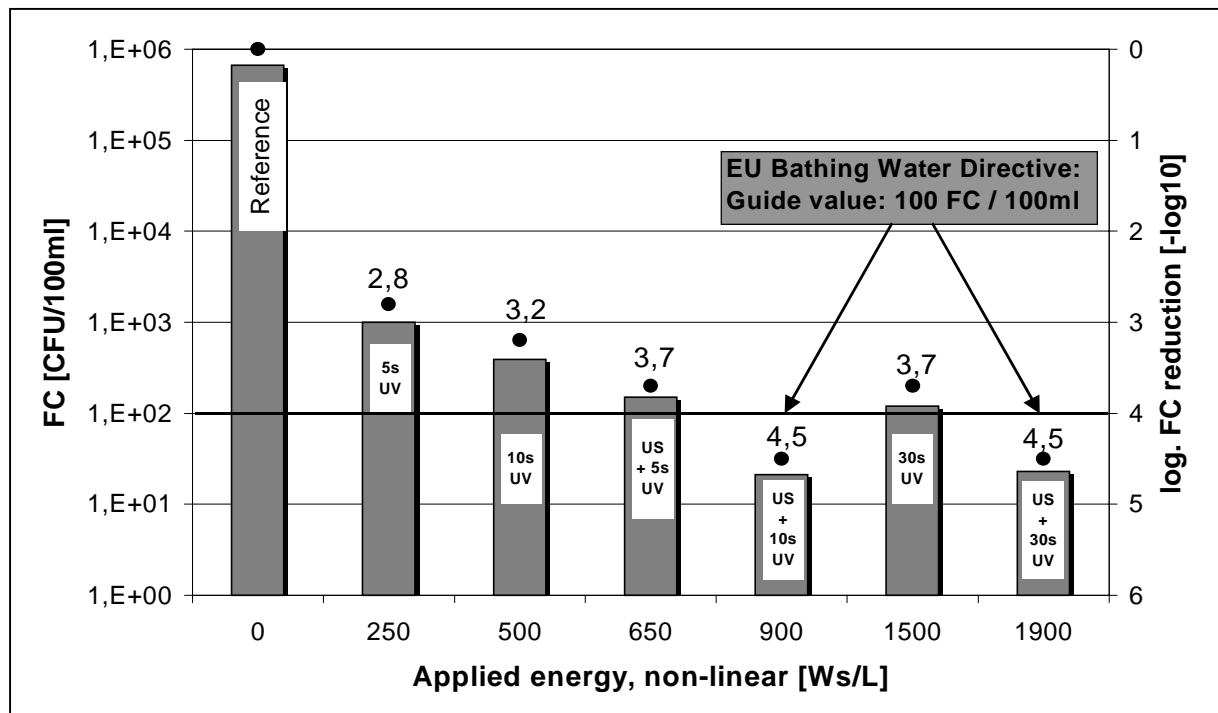


Figure 7: Improved UV disinfection (density: 50 W/L) by ultrasonic pre-treatment (sonication time: 5 s, density: 80 W/L) to meet the Bathing Water guide value

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