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# Experimental study on the disinfection efficiencies of a continuous-flow ultrasound/ultraviolet baffled reactor

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ABSTRACT

A self-designed continuous-flow ultrasound/ultraviolet (US/UV) baffled reactor was tested in this work, and the disinfection efficiency of secondary effluent from a wastewater treatment plant (WWTP) was investigated in terms of the different locations of ultrasonic transducers inside the reactor under similar input power densities and specific energy consumptions. Results demonstrated that the two-stage simultaneous US/UV irradiation in both chambers 2 and 3 at a flow rate of 1200 L/h performed excellent disinfection efficiency. It achieved an average feacal coliforms concentration of 201 ± 78 colony forming unit (CFU)/L in the effluent and an average of (4.24 ± 0.26) $\log_{10}$ reduction. Thereafter, 8 days of continuous operation was performed under such a condition. A total of 31 samples were taken, and all the samples were analyzed in triplicate for feacal coliforms analysis. Experimental results showed that feacal coliforms concentrations remained at about 347 ± 174 CFU/L under the selected optimum disinfection condition, even if the influent concentrations fluctuated from $3.97 \times 10^5$ to $3.57 \times 10^6$ CFU/L. This finding implied that all effluents of continuous-flow-baffled-reactor with simultaneous US/UV disinfection could meet the requirements of the discharge standard of pollutants for municipal WWTP (GB 18918-2002) Class 1-A (1000 CFU/L) with a specific energy consumption of 0.219 kWh/m$^3$. Therefore, the US/UV disinfection process has great potential for practical applications.



## 1. Introduction

In 2002, a newly revised Chinese national standard (Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant, GB18918-2002) was released, and a feacal coliform was included in the standard. For Class 1-A, less than 1000 colony forming unit (CFU)/L is required [1]. Therefore, disinfection effectively removes pathogenic microorganisms and protects water bodies and human beings. Currently, chlorination is a well-established technology that has been widely used in China for many years. However, strict safety measures should be used to avoid the threat to plant workers and the public. Therefore, these measures lead to complex management. Moreover, chlorination requires a relatively long contact time (normally 30 min) compared with ultraviolet (UV) disinfection [2]. The toxic effects of chlorination on living organisms and chlorination by-products, such as halogenated hydrocarbons, bromide, formaldehyde, acetaldehyde and methylglyoxal are suspected to be harmful to the environment and to humans [3–6], these toxic effects are a great concern. By contrast, UV disinfection effectively removes most pathogens without contributing to the formation of toxic by-products [7,8], and it has been applied to many newly-built wastewater treatment plants (WWTPs) or in retrofitting existing WWTPs. Nevertheless, UV disinfection is easily affected by water quality, such as turbidity, color, and suspended solids [9]. Therefore, improving the current UV disinfection technology is required for better practical application.

Ultrasound (US) is a non-medical technology, and many authors have reported the usage of sonication in water and wastewater effluent treatment, biotechnology and food processing [10–12]. Cavitation bubbles produce mechanical, chemical and heat effects that inactivate microorganisms, and the mechanical effects are considered dominantly responsible for the process [13,14]. However, US disinfection alone always requires high specific energy consumption [15,16]. Therefore, for effective decontamination and realistic application, US is recommended to be applied with a conventional disinfectant. Many hybrid techniques have been reported in the literature, including the combination of chlorine, ozone, or UV [17–19]. Reportedly, bacteria flocs can be deagglomerated through mechanical shear force of low frequency US, consequently changing the particle size distribution. Moreover, the percentage of particles larger than 50 μm could decrease from

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63% to 5% at a US input power density of 30 W/L for 30 s. Therefore, as more pathogens are exposed to disinfectants, the disinfection effects are improved [20]. Furthermore, US-produced cavitation can motivate the sonochemical oxidation called the sonophotocatalytic process in some cases; this process has been proven effective in organic matter removal [21,22]. Cavitation has also been considered to be more efficient with the assistance of nanomaterials and hydrogen peroxide [23].

To date, US is proved to have synergistic effects when combined with UV disinfection, but most related studies were performed in the laboratory scale and under batch condition [20,24,25]. Research conducted under a continuous condition is limited. In Italy, a pilot-scale plant using a plug-flow US and UV simultaneous disinfection reactor continuously operated in a WWTP for four days. The results showed that *Escherichia coli* concentrations in disinfection effluents could meet the Italian standard for reclaimed water reuse (10 CFU/100 ml) when a US unit with a dose of 1400 W and a UV unit with a dose of 1656 mJ/cm$^2$ were applied for 15 min. US was also proved to help clean UV lamps in the previous pilot-scale plant investigation [26]. However, the specific energy consumption in this test was about 5.35 kwh/m$^3$, which implies a high operation cost. Therefore, this system requires process optimization to reduce specific energy consumption.

In the present study, based on previous experimental results and research analysis, a continuous-flow US/UV baffled reactor was developed and designed. Secondary effluent from a municipal WWTP was then used as feeding water. The objectives of this study are as follows: (1) to investigate the disinfection efficiency of a continuous-flow US/UV baffled reactor under different locations of ultrasonic transducers and UV lamps; (2) to evaluate the disinfection efficiency under a specific energy consumption; and (3) to test the disinfection reliability and stability of the optimal condition under a continuous long-term operation. All disinfection efficiencies were evaluated on the basis of bacteria inactivation (feacal coliform as an indicator). The results could provide useful information to retrofit the current UV disinfection process.

## 2. Materials and methods

### 2.1. Feeding wastewater

Secondary effluent from a municipal WWTP with a design capacity of $5 \times 10^4$ m$^3$/d was used as feeding water in this investigation. Oxidation ditch was the main treatment process. The system included processes such as screening and anaerobic hydrolysis. The main parameters of the secondary effluent are shown in Table 1.

Disinfection was essential before discharge because of the high feacal coliforms concentrations ($3.67 \times 10^5$–$9.48 \times 10^7$ CFU/L). UV could be used for disinfection; but the suspended solid contents fluctuated with the maximum concentration of 18 mg/L. Therefore, a US/UV disinfection process was introduced and tested in a WWTP as an alternative solution.

**Table 1**
Main parameters of the secondary sedimentation tank effluent.

| Source | Secondary effluent form WWTP | Average value ± S.D. of 92 samples |
|---|---|---|
| pH | 7.55–8.51 | 7.95 ± 0.15 |
| CODcr, mg/L | 14–58 | 30.07 ± 8.07 |
| Suspended solid (SS), mg/L | <5 (90%), max. 18 | – |
| Color | 38–58 | 45.8 ± 3.37 |
| Fecal coliform, CFU/L | $3.67 \times 10^5$–$9.48 \times 10^7$ | $4.71 \times 10^6 \pm 3.69 \times 10^6$ |

*Note:* S.D. means standard deviation.

### 2.2. US/UV disinfection plant setup

A US/UV baffled reactor (Fig. 1) was designed and manufactured to investigate the disinfection effectiveness of different ultrasonic transducer locations and specific energy consumptions. The continuous-flow US/UV baffled reactor had a size of $600 \times 200 \times 1200$ mm ($L \times B \times H$), and an effective volume of 96 L. Two baffles were inserted into the reactor with a distance of 200 mm from each other. The baffles divided the reactor into three equal-volume chambers. Each chamber had a size of $200 \times 200 \times 800$ mm ($L \times B \times H$) and a volume of 32 L. One more baffle was installed in the middle of chamber 1 to help change the water flow direction and avoid short-cut flow.

Ultrasonic transducers were set at the bottom outside the three chambers, and UV lamps were installed in the second and third chambers. A geometrical location of the US transducers and the UV lamps is presented in Fig. 2 for better understanding.

Ultrasonic transducers and UV lamps were independently controlled. Each US was designed at a frequency of 28 kHz and a maximum power of 60 W (Yitian Ultrasonic Technology Co., Ltd, Baoding, Hebei Province, China), and the maximum total power input was 600 W with 10 ultrasonic transducers. Sonication energy consumption could be controlled from 10% to 100% by adjusting the input power. Five low-pressure Hg UV lamps (15 mm in diameter and 846 mm in length, CNLIGHT Company Ltd., Shenzhen, Guangzhou Province, China) were installed in each of the second and third chambers (80 W each; total power, 800 W). Each lamp could be separately controlled with on–off buttons. A power meter (LCDG-ZJ1-62010) was used to measure the real input power of each unit.

Throughout the experiment, raw water from the secondary settling tank of the WWTP was continuously fed into the reactor using a submerged pump. The influent flow rate was measured using a flow meter, and the effluent was discharged into the effluent channel of the WWTP after disinfection. Water samples of the influents and effluents were collected according to planned time intervals.

### 2.3. Experimental scenarios

The experiments consisted of three parts. First, disinfection efficiency was investigated under different operation conditions based on the ultrasonic transducer and UV lamp locations. Second, disinfection efficiency was evaluated under various specific energy

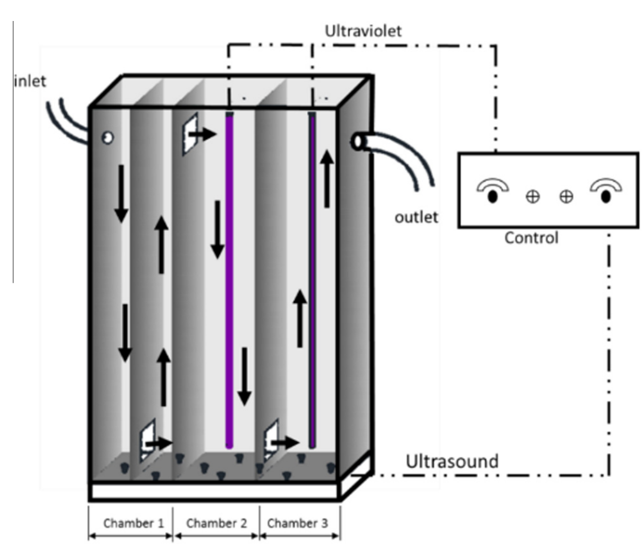


**Fig. 1.** Schematic longitudinal section of the US/UV reactor.