Employing Ultrasonic Techniques to Improve Biological and Physiochemical Characteristics of Industrial Pollutants

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ABSTRACT

Objective: Ultrasonic waves are an eco-friendly, efficient technology due to their simple equipment, rapid reaction, lack of secondary pollution, sustainability, and use in industrial wastewater degradation. They have also been widely studied for degrading pollutants and enhancing biological treatment processes. Newly discovered pollutants from the pharmaceutical and agricultural industries, including hormones, antibiotics, dyes, and other pharmaceutical drugs, have become a major source of environmental problems and a threat to all living organisms and water bodies.

Materials and Methods: Samples of wastewater from vegetable oil factory basins in Baghdad were collected, followed by ultrasonic treatment (40 kHz) for four different periods (15, 30, 60, and 90 min), with varying energy (low, medium, and high). The pH, total dissolved solids, and chemical oxygen demand variables were measured, and the effect of ultrasound on the bacterial content of the polluted water was studied before and after treatment.

Results: The pH value increased after exposure to an ultrasound wave from an initial value (control) of 7.2 to 7.6, 8.1, and 7.8, respectively, with all cases (low, mid, and high), for 30 min of exposure. All (low, mid, and high) show an increase in Total Dissolved Solids from a control value of 1470 ppm to 1755, 1860, and 1944 ppm, decreasing to 1460, 1320, and 1185 ppm after 30 and 90 minutes of exposure, respectively. However, the Chemical Oxygen Demand value after being exposed for (15, 30, 60, and 90) min at (low, mid, and high) power, was reduced with reduction ratios (6.81, 31.8, and 34.09%), (43.1, 52.2, and 47.7%), (45.4, 52.2, and 56.8%), and (59.09, 61.3, and 68.1%), respectively. The number of bacterial colonies decreased with exposure time and energy strength. 100% removal of coliform bacteria after 90 min is due to bacterial cell damage.

Conclusion: We conclude that it is possible to employ green sustainability techniques to reduce the components of liquid waste discharged into the aquatic environment, water quality, and biodiversity.

Keywords: Ultrasonic technology, COD, TDS, pH, Coliform bacteria.

1. INTRODUCTION

Rapid industrialization and numerous anthropogenic activities have increased the potential for pollution, leading to a growing focus on agro-industrial wastewater treatment. Wastewater released into the environment without control will harm people, animals, and plants [1]. In addition, it can contaminate both surface and groundwater due to its high pollutant load. A large amount of wastewater is also present in the surrounding environment, and industrial wastewater must be kept out of the discharged effluents to prevent pollution. Many aromatic compounds with large molecular weights resist biodegradation based on their molecular structure [2].

Water quality is determined by its biological and physicochemical characteristics. It is unsuitable for human consumption due to changes in pH, temperature, and the

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presence of elements. Furthermore, water quality is also influenced by the hydrological attributes of water sources, geological processes, geochemistry, and features of the surrounding environment [3].

In green chemistry, ultrasonic technology (US) is one of the advanced oxidation processes (AOP) in aqueous solution, used alone or combined with other oxidizing agents, such as O_3/US, H_2O_2/US, and UV/US, to produce free radicals and play a crucial role and influence in chemical and biological processing of the chemical industries, as shown in references [4] and [5]. In addition, researchers in [6] stated that it becomes increasingly effective in degrading organic pollutants, destroying odors and colors. The US pressure wave caused the bubble to nucleate, grow, and finally collapse, oxidize, and produce hydroxyl radicals [7].

AOP technology used in the US has gained the attention of many researchers because it degrades pollutants without requiring the addition of other catalysts, as studied in the research [8, 9]. In contrast, physical and chemical effects occur after using US technology on pollutants, as [10] and [11]. Therefore, researchers responsible for preparing articles in references [12], [13], and [14] stated that AOP techniques determine the concentration of degraded organic pollutants depending on the liberated free radicals as powerful oxidizing agents (HO•), produce carboxylic acids, then transform into carbon dioxide and water by breaking down chemical compounds rather than using solar energy and other chemicals. However, AOP lies in mineralizing all types of pollutants or completely oxidizing them into harmless, inorganic products such as CO_2 and H_2O. So is an environmentally friendly technology [15].

The mechanism of AOP lies in a series of steps, including, first, the formation of high amounts of active oxygen through oxidation reactions, which are formed through either chemical reactions or the use of an energy source such as the US, electrical energy, and UV radiation, or the use of a specific catalyst, and finally, the oxidants formed react with the pollutants and form intermediates [16]. The intermediate compounds from the previous step, which are characterized as biodegradable, are then mineralized and transformed into stable inorganic compounds such as carbon dioxide, water, and salts, as mentioned in references [17, 18]. Inorganic salts can be treated using methods, chemical methods (ion exchange, chemical precipitation), physical methods (sedimentation, filtration), and biological methods, such as anaerobic digestion and activated sludge.

The criteria for measuring the rate of pollution in water exposed to treatment with these techniques are based on many physical and chemical variables before and after treatment, including the rate of dissolved oxygen (DO), pH, temperature, conductivity, total dissolved solids (TDS), metals, chemical and biological oxygen demand (BOD and COD), and heavy metal concentration [19]. Biological methods are cost-effective and eco-friendly, and thus can serve as an economical and efficient alternative for the large-scale synthesis of silver nanoparticles [20] and [21].

The present study aims to improve the efficiency of industrial wastewater using low-cost and clean-use ultrasound technology by increasing the concentrations of TDS, reducing the COD and the vital number of bacteria harmful to humans when treated for periods ranging from 30 to 90 minutes, as this type of green technology can be applied to improve the efficiency of many industrial pollutants before they are released into the aquatic environment.

2. MATERIALS AND METHODS

2.1. Ultrasound treatment of wastewater

Samples of industrial polluted water were collected from the basins containing vegetable oil factory residue in Baghdad before being released into the aquatic environment. Then the treatment process is done by using a US instrument (40 kHz) (JAC, multi-frequency ultrasonic bath, 4020, Korea) [22], for different durations of time (15, 30, 60, and 90) min, with the variance of power (low, mid, and high). The US process was in a glass vessel (25 and 250 ml). During sonication, the wastewater temperature increased gradually with time of exposure. Electric conductivity (EC) (µs/cm), pH, and TDS (ppm) of the sample were measured by the electrode-based probe (WTW, Germany), and the COD (ppm) of the samples was measured.

2.2. Total count of bacteria

Fifty µL of the wastewater was spread on the surface of nutrient agar (Hi-Media, India), before and after being treated with the US (40 kHz) for (15, 30, 60, and 90) min, with a variance of power (low, mid, and high), then incubated in petri dished for 24 h at 37 ºC. Finally, the total count of bacteria, as in the research [23].

2.3. Coliform test of wastewater sample

Fifty µL of the wastewater was spread on the surface of eosin methylene blue (EMB) agar (Hi-Media, India), before and after being treated with the US (40 kHz) with the variance of power (low, mid, and high) for (15, 30, 60, and 90) min, as mentioned in reference [24], colonies were calculated after incubating for 24 h at 37 ºC.

3. RESULTS AND DISCUSSION

3.1. Physical and chemical characterization of wastewater

Figure 1 shows the maximum pH values recorded after 30 min of exposure. In all cases, the initial value (control) of 7.2 increased to 7.6, 8.1, and 7.8.

The increase in the pH value after 30 min of exposure of the environmental pollutants under study to ultrasound waves in its three states (low, mid, and high) indicates the physical, chemical, and biological changes that occur in the liquid material exposed to ultrasound waves directly, as the pH level rises by the production of free radicals from OH at higher levels than other free radicals in the liquid medium exposed to ultrasound waves, and thus the pH level increases concerning this type of free radicals, and this came following what was mentioned in references [25] and [26].

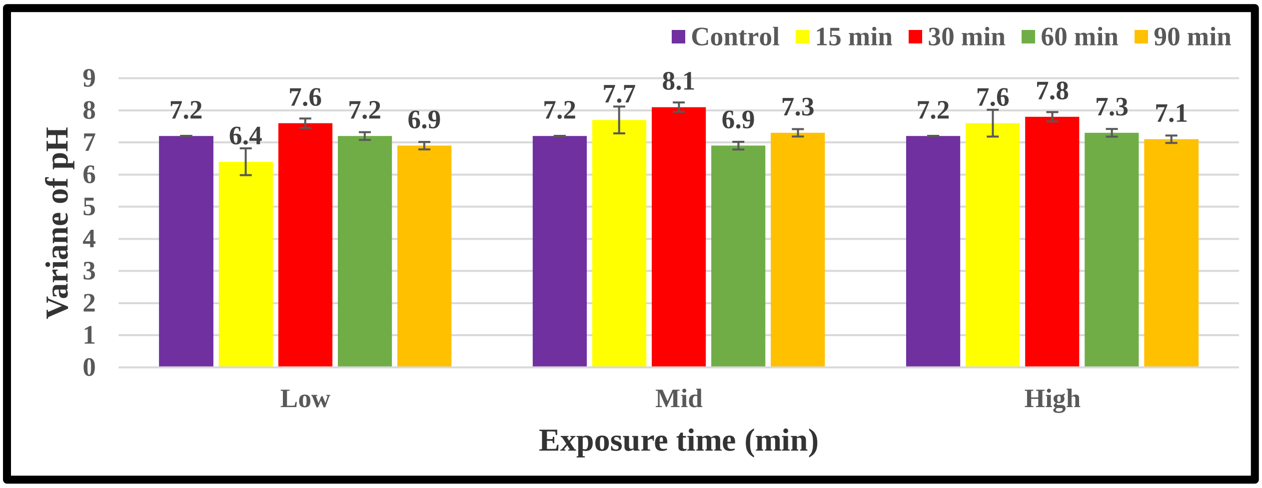

Fig. 1: Effect of ultrasonic waves on wastewater pH after exposure to different durations of ultrasonic waves

According to Figure 2, after treatment for 30 min, the TDS increased in all cases (low, mid, and high) from a control value of 1470 ppm to (1755, 1860, and 1944) ppm, respectively. It is possible to increase the solid solubility through the US treatment. While treating for 90 min at a high temperature, the values begin to decrease after exposure to variable power (mid and high), respectively, from a control value of 1470 ppm to (1320 and 1185) ppm, respectively (Table 1).

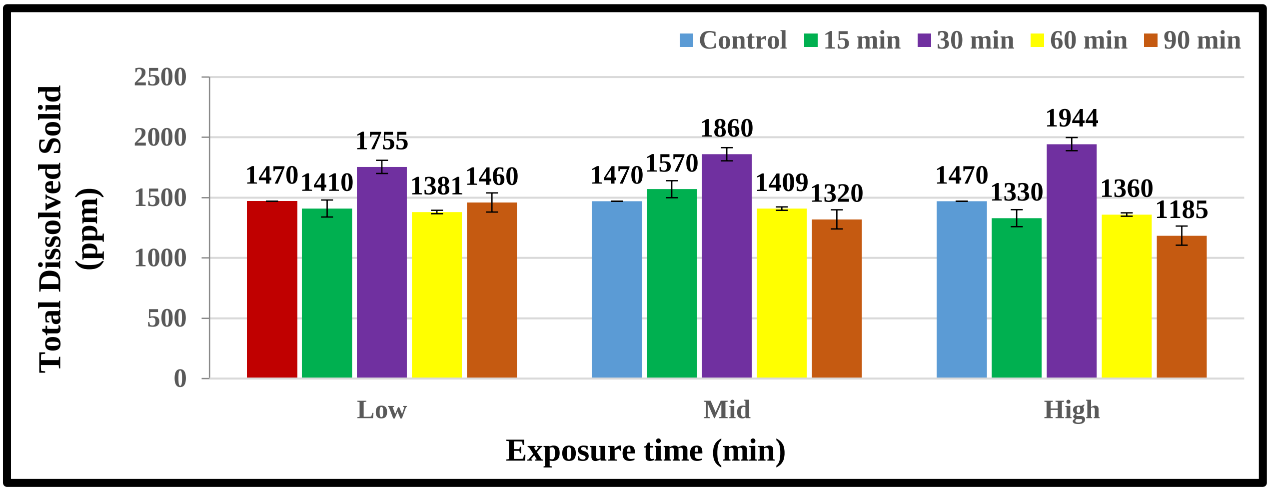

Fig. 2: Effect of the ultrasonic wave on wastewater TDS after exposure to different times of ultrasonic waves

Table 1: Measurement of physical characterization of wastewater after different times

Measurement of physical wastewater characterization before and after exposure to Ultrasound waves (40 kHz) with a variance of power, for different times												
Control	**15 min**			**30 min**			**60 min**			**90 min**		
	Low	**Mid**	**High**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**
pH 7.2	6.4	7.7	7.6	7.6	8.1	7.8	7.2	6.9	7.3	6.9	7.3	7.1
EC (µs/cm) 12.26	12.18	12.15	12.16	12.75	12.40	12.22	11.8	12.2	12.1	12.28	12.24	12.2
TDS (ppm) 1470	1410	1570	1330	1755	1860	1944	1381	1409	1360	1460	1320	1185

Total dissolved solids (TDS) are the amount of organic and inorganic materials, such as metals, minerals, salts, and ions, dissolved in a particular volume of water; TDS is essentially a measure of anything dissolved in water that is not an H_2O molecule. Total dissolved solids can come from sources such as sewage, water treatment chemicals, agricultural runoff, or industrial wastewater. Natural sources, like soils and rocks, may also contain TDS. Urban runoff, or the flow of rainwater in urban landscapes, can carry TDS, and the pipes and plumbing materials used to water a home may be a source.

After US wastewater treatment, the TDS value can decrease for the following reasons: organic materials dissolved in the water may become dimers or trimmers; organic materials may break down into simple molecular compounds [26], while the results published in the reference [27] indicate that any microorganisms or algae present, they may be broken down when exposed to US waves, which will cause the TDS value to decrease as a result of high-frequency US waves.

According to the results shown in Figure (3), the percentage of COD reduction value after treating wastewater with US for (15, 30, 60, and 90) min in all cases (low, mid, and high) was (6.81, 31.8, and 34.09) %, (43.1, 52.2, and 47.7) %, (45.4, 52.2, and 56.8) %, and (59.09, 61.3, and 68.1) %, respectively. This indicates that microorganisms and degradable organic matter from wastewater pollutants lower COD concentrations [26]. An increased reduction in the COD value refers to the large number of cavitation bubbles generated in the solution when a large amount of US power enters a system.

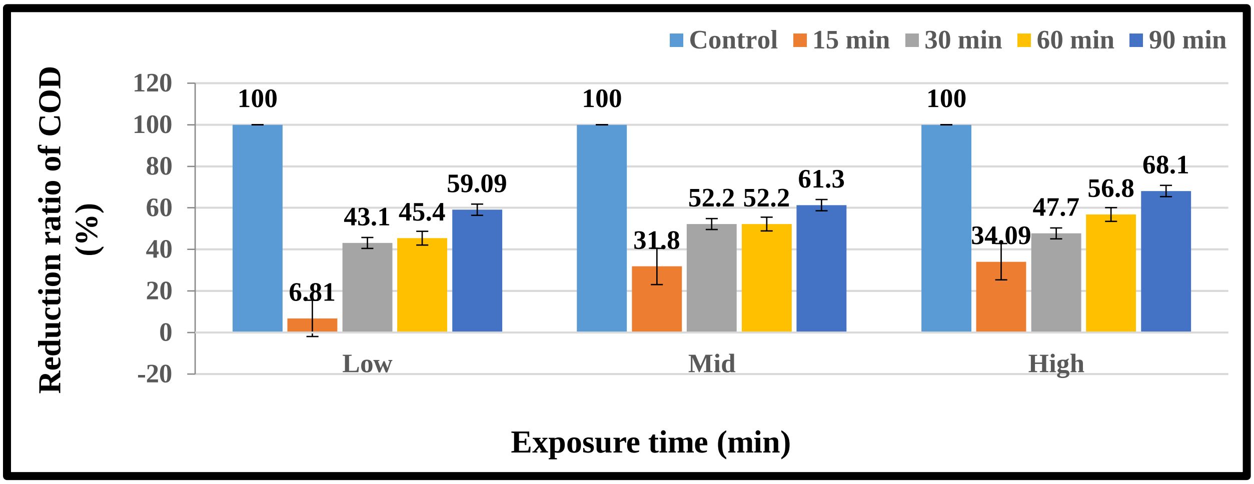

Fig. 3: Reduction value of wastewater COD after exposure to different times of ultrasonic waves

Many bubbles will form a barrier to the transfer of energy through the liquid, and an increase in temperature will raise the vapor pressure of a medium, leading to easier cavitation but less violent collapse. Hence, as studied in a reference [28], a decrease in viscosity and surface tension will inhibit the effect of US energy on the source.

Meanwhile, the EC measurement results indicate no potential energy and US exposure duration Table 1.

3.2. Determination of the bacterial content of wastewater

Different bacterial colonies appeared when the plates were incubated at 37 °C overnight before the industrial wastewater was exposed to US waves. Results show that it is possible to decrease the number of microorganisms in the wastewater, depending on exposure time, frequency, intensity of the US waves, and the type of microorganisms. Bacterial colonies were damaged with increased exposure time to US waves and power densities, reaching 90% for 15, 99.90% for 90, with high power exposure, as described in Table 2. The inactivation mechanism damages the cell wall, was 99% at 45 min [29].

Table 2: Viable count of total bacteria after treating with ultrasonic waves at different times

Percentage of killing bacteria (50 µL) before and after exposure to ultrasound waves (40 kHz), with a variance of power and duration times, after growing on nutrient agar (%)					
Control	**1060**	**15 min**	**30 min**	**60 min**	**90 min**
Low		48.11	50.94	57.83	72.26
Mid		64.15	83.30	91.88	99.52
High		90	99.15	99.71	99.90

On the other hand, reference [30] reported that with the device operating continuously for 5 min at a frequency of 20 kHz, the number of bacteria was reduced by more than 60%. The number of microorganisms was 80% lower than that of the control group after 30 minutes of exposure to a 40 kHz US wave operation. The outcomes demonstrate that the US disintegration process can be applied in municipal wastewater treatment facilities.

Exposure to the US leads to cell wall damage, oxidation of amino acids inside, and mutations and modifications in DNA. On the other hand, reference [31] considers green technology to be the removal of environmental pollutants.

Many researchers have conducted experiments using US technology as a disinfectant, which inhibits the growth of some microorganisms and kills others, as discussed in reference [32]. The mechanism of action of this technology, explained in reference [33], is to increase pressure and temperature, attack chemicals by generating free radicals, and destroy cell membranes due to the collapse of bubbles formed by the action of this technology, in addition to the spread of chemical oxidants inside the microorganism cell.

3.3. Elimination of coliform bacteria

Wastewater contains pathogenic microorganisms, which, if they get into the environment, can cause bacterial diseases. The lack of use of the wastewater disinfection process raises concerns about the sanitary quality of wastewater leaving treatment plants, as coliform bacteria are found in water samples. A US wave is defined as a frequency that generally exceeds 20 kHz, which propagates through various types of media with speeds that are affected by the medium. The speed of sound waves in an intermediate medium depends on the compressibility and density of the medium.

Table 3 shows the effectiveness of ultrasound waves with varying powers (low, mid, and high) in damaging coliform bacteria when exposed to periods (15, 30, 60, and 90) min, with percentages more than 90% when exposed for 30 and 60 minutes, and none are present for 90 min.

Table 3: Viable count of coliform bacteria after treatment of industrial wastewater with ultrasonic waves at different times

Percentage of killing coliform bacteria (50 µL) before and after exposure to ultrasound waves (40 kHz), with a variance of power and duration times, after growing on EMB agar (%)					
Control	**760**	**15 min**	**30 min**	**60 min**	**90 min**
Low		56.57	93.42	98.55	100
Mid		65.13	99.07	99.21	100
High		88.68	99.86	100	100

Consistent with the results in reference [29], after 15 min of sonication, bacterial density was reduced by 1.85 Log 10 MPN/100 ml for *Escherichia coli* and 3.16 Log 10 CFU/ml for *Bacillus subtilis*, 30 min, no CFU/ml of *B. subtilis* was observed in municipal wastewater and, after 45 min, the reduction of total and fecal coliforms was practically 6.45 Log 10 MPN/100 ml. The results were also consistent with what was mentioned in the source [34], which states that 100% of *E. coli* bacteria are removed when industrial wastewater is exposed to the US for 90 minutes. Bioactive compounds from fruits contained several bioactive compounds with promising bactericidal properties against tested strains of both Gram-positive and Gram-negative pathogenic bacteria [35].

4. CONCLUSIONS

Appropriate measures must be taken to prevent river pollution. To maintain a healthy environment and ecosystem of the river and its surrounding areas, awareness must be raised among the local population about water pollution and its harmful effects on public health. All samples of industrial wastewater indicate that exposure to ultrasound waves results in a decrease in TDS and pH as the time of ultrasound wave exposure increases. This may explain why low-TDS treated water can be reused for agricultural purposes. Ultrasound in wastewater treatment emerges as a comprehensive and promising approach, offering a spectrum of benefits, including mass transfer and cell permeability to promote enzyme-catalyzed reactions and influence cell growth.

Acknowledgment

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Conflict of interest

The authors declare that they have no conflict of interest.

Abbreviations

US	Ultrasonic
AOP	Advanced Oxidation Processes
UV	Ultraviolet
DO	Dissolved Oxygen
TDS	Total Dissolved Solids
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
CFU	Colony Forming Unit
MPN	Most Probable Number
EC	Electric Conductivity

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توظيف تقنيات الموجات فوق الصوتية لتحسين الخصائص البيولوجية والفيزياوية والكيمياوية للملوثات الصناعية

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ملخص

المقدمة: الموجات فوق الصوتية هي تقنية فعالة وصديقة للبيئة بسبب معداتها البسيطة، ورد فعلها السريع، وقلة التلوث الثانوي، والاستدامة، وكفاءة تدهور مياه الصرف الصناعي. كما تمت دراستها على نطاق واسع لتحليل الملوثات وتعزيز عمليات المعالجة البيولوجية. أصبحت الملوثات المكتشفة حديثا من الصناعات الدوائية والزراعية، بما في ذلك الهرمونات والمضادات الحيوية والأصباغ وغيرها من الأدوية الصيدلانية، مصدرا رئيسيا للمشاكل البيئية وتهديدا لجميع الكائنات الحية والمسطحات المائية.

طرق العمل: تم جمع عينات من مياه الصرف الصحي لاحواض معمل الزيوت النباتية في بغداد، وأتبعتها المعالجة بالموجات فوق الصوتية (40 كيلو هرتز) لأربعة فترات زمنية مختلفة (15، 30، 60، 90) دقيقة، مع تباين الطاقة (منخفضة ومتوسطة وعالية). تم قياس متغيرات الاس الهيدروجيني والمواد الصلبة الذائبة الكلية والمتطلب الكيمياوي للاوكسجين، وتمت دراسة تأثير الموجات فوق الصوتية على المحتوى البكتيري للمياه الملوثة قبل وبعد المعالجة.

النتائج: ارتفعت قيمة الاس الهيدروجيني بعد التعرض لمدة 30 دقيقة للموجات فوق الصوتية من القيمة الأولية (سيطرة) 7.2 إلى 7.6 و8.1 و7.8 على التوالي، في جميع حالات الطاقة (المنخفضة والمتوسطة والعالية). وشهدت جميع الحالات (المنخفضة والمتوسطة والعالية) زيادة في إجمالي المواد الصلبة الذائبة من 1470 جزء في المليون إلى 1755 و1860 و1944 جزء في المليون، ثم انخفاض إلى 1460 و1320 و1185 جزء في المليون بعد 30 و90 دقيقة من التعرض على التوالي. ومع ذلك، تم اختزال قيمة المتطلب الكيمياوي للأوكسجين بعد التعرض لمدة (15، 30، 60، و90) دقيقة عند الطاقة (المنخفضة والمتوسطة والعالية) بنسب اختزال (6.81، 31.8، و34.09٪)، (43.1، 52.2، و47.7٪)، (45.4، 52.2، و56.8٪)، و (59.09، 61.3، و68.1٪)، على التوالي. إلى جانب ذلك، انخفض عدد المستعمرات البكتيرية مع زيادة وقت التعرض وقوة الطاقة، الى نسبة ازالة 100٪ من بكتريا القولون بعد التعرض لمدة 90 دقيقة بسبب تلف الخلايا البكتيرية.

الاستنتاجات: نستنتج أنه من الممكن توظيف تقنيات الاستدامة الخضراء لاختزال محتويات النفايات السائلة التي يتم تصريفها في البيئة المائية والحفاظ على جودة المياه والتنوع البيولوجي.

الكلمات الدالة: تقنية الموجات فوق الصوتية، متطلب الاوكسجين الكيميائي، المواد الصلبة الذائبة الكلية، الاس الهيروجيني، بكتريا القولون.

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