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EFFECT OF ULTRASOUND TECHNOLOGY ON WASTEWATER TREATMENT EMPHASIZING ON HEALTH ISSUE

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ABSTRACT

Background: *Wastewater and sludge have huge pathogenic substances. So far, various physical and chemical processes have been used for disinfection, including chlorination, ozone and ultraviolet radiation. The use of this type of disinfectants is currently decreasing due to the hazards that they pose such as byproducts of disinfection, including carcinogenic Trihalomethanes. Nowadays, researchers have begun to use other processes that create less risks such as ultrasound technology. Ultrasound waves by breaking the cell wall causes reducing pathogenic populations and eliminating the risk of disinfection byproducts and are one of the newest methods for disinfection in water and wastewater treatment plants. For physical, chemical and biological effects of ultrasound waves on plants, ultrasound radiation results in the rotational movement of the protoplasm in individual cells and affects the growth rate of plants. In humans, the hypothesis is that exposure to ultrasound causes subsequent electrolytic balance changes in the nerve tissue and increases blood glucose levels. Ultrasound waves cause bacterial colony damage and thinning of the cell wall and the release of the cytoplasmic membrane. Mechanical effects of ultrasound waves can be used for water and wastewater disinfection.*
Methods: *This research is a descriptive-analytic study that was carried out in a batch experiment. The goal of this research is to investigate the effect of ultrasonic waves on disinfection in South Tehran wastewater treatment plant.*
Results: *The results showed that by increasing the time and density of the ultrasound, the rate of removal of E.coli increased. Also, the optimal sonification time was 30 minutes and the optimal ultrasound density was 2.5 watts per milliliter at a frequency of 20 kHz. E.coli removal rate in these conditions was more than 99%.*
Conclusion: *According to the results of this study, the use of ultrasound waves has a significant effect on the elimination capacity of Escherichia coli and can be used as an appropriate alternative for stabilization and disinfection in wastewater treatment plants.*

Keywords: *Ultrasound, Health, Wastewater, Treatment, Cavitation*

INTRODUCTION

The rapid expansion of biotechnology science has always attracted new methods and solutions to further development of the performance of biological processes. Also, based on the principles of engineering and green science, biotechnology not only changes the various fields of science, such as medicine, agriculture, chemistry, but also increases the chance to produce new services [1].

It is believed that Green Technology must have its high performance, low instrumental conditions, and in particular, reduced process time in comparison with other techniques and economic performance. As a quick way, over the past few years, the use of ultrasound that has a higher sound level than humans hearing, especially at low frequencies (10-60 kHz) has been considered in upgrading biotechnology processes. The US National Aeronautics and Space Administration (NASA) uses this method to treat water used on spacecraft and its space station [1].

Activated sludge is one of the common processes of biological treatment of sewage. In this process, organic pollutants are converted to carbon dioxide and water, which is associated with the production of excess microbial biomass that is known as excess active sludge [2]. Wastewater and sludge have several pathogens. The most important indicator of the presence of pathogens in wastewater and sludge are coliforms [3]. So far, various physical and chemical processes have been used to disinfect wastewater and sludge, including chlorination [4], ozone [5] and ultraviolet radiation [6]. The use of this type of disinfectants is currently decreasing due to the hazards that they pose. For example, you can mention the dangers of using chlorine. This substance poses a great deal of danger to the health and safety of wastewater treatment plant personnel and surrounding communities, and produces side-effects of disinfection, including trihalomethanes and halostasic acids, which have carcinogenic effects [7].

So nowadays, researchers have begun on the use of other processes that create less risks. One of these processes is ultrasound waves. Ultrasound waves, like ozone or thermal and biological methods (such as hydrolysis of enzymes) [8, 9, 10] by breaking the cell wall causes reducing pathogenic populations and eliminating the risk of disinfection side products [11]. These waves at 20 to 200 kHz frequencies and high energy levels are one of the newest methods for disinfection in water and wastewater treatment plants.

Ultrasound Waves

In Sonochemistry, ultrasound is used as a source of energy for various chemical processes. The ultrasound was first produced by Galton, who was studying the human and animal hearing threshold. The basis of today's ultrasound production dates back to 1880 to discover the effect of piezoelectric by Curie. The first commercial application of ultrasound waves was made in 1917 [1]. When a high-power ultrasound is used in low-frequency ultrasound systems, it is possible to make chemical changes due to the cavitation phenomenon. The cavitation phenomenon was first detected and reported in 1895. The use of ultrasound waves has been considered for the decomposition of organic matter in water and sewage since 1990. Ultrasound has many uses in biochemistry, biology, dentistry, geography, medicine, and the environment. The ultrasound spectrum for each application is different. The use of ultrasound can be divided into two parts according to frequency [1]. Figure 1 shows the naming of sound wave frequencies.

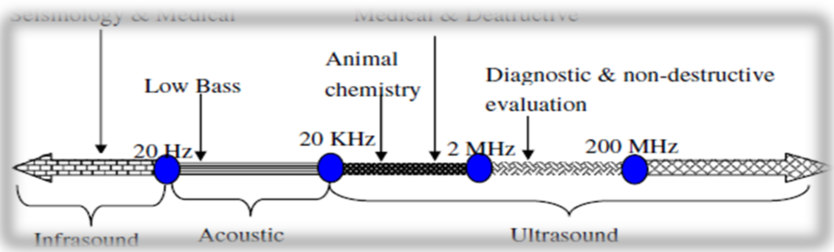

Figure 1- Different sound waves at various frequencies [1]

Cavitation phenomenon

When a wave of ultrasound is released in a liquid, the repeated pattern of becoming compressed and decompression happens due to the movement of the sound wave. Due to the reduction of the pressure in the areas where congestion occurs, fine bubbles form. These fine bubbles are called cavitation bubbles, which in fact carry liquid vapors and gases that were previously dissolved in the liquid. When the wave moves, fine bubbles oscillate under positive pressure. So they get unstable before they collapse. Cavitation is a phenomenon in which small bubbles form in the liquid phase and expose to an unstable extent, so they quickly dissipate. The disintegration of bubbles often causes local heat up to 5000 degrees Celsius and a pressure of up to 2000 atmospheres, which is so high that it produces light. The sudden and severe disintegration of millions of small bubbles produces powerful hydro mechanical shear forces [1, 10]. Figure 2 shows the process of creation of cavitation bubbles.

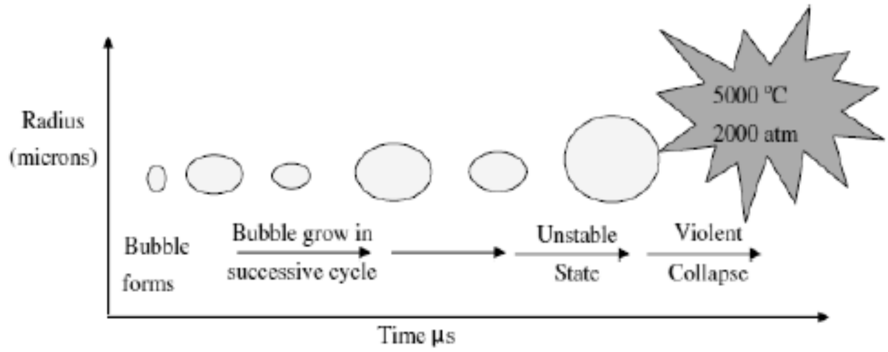

Figure 2- The process of creation of cavitation bubbles [12]

The effects of the cavitation phenomenon on fluids can be summarized as follows:
Extremely high hydro mechanical shear stress causing mechanical damage to the compounds. Formation of H ° and OH ° free radicals that can facilitate chemical reactions to degrade organic pollutants. Further destruction of specific compounds within the cavitation bubbles, since the hydrophobic boundary layer formed in the media allows the penetration of volatile substances into cavitation bubbles, and subsequently these substances are involved in reactions formed within the bubble. Advancement of chemical reactions due to high pressure and high local temperature [1, 10].

Advantages of ultrasonic waves are such as: No producing secondary organic compounds, higher dewatering, disintegration of toxic contaminants, breaking organic compounds, breaking complex compounds into simpler forms, compact design, no need to add chemicals, no fouling problems [1, 10].

The effect of ultrasound waves on humans, plants and the environment

Many studies have focused on the physical, chemical and biological effects of ultrasound. Among the studies on plants, it was observed that ultrasound radiation resulted in the rotational movement of the protoplasm in individual cells. This movement is difficult to detect at low levels of ultrasound energy,

but easily detectable at high levels. In all studies, effect of ultrasound waves on plants was determined to affect the growth rate of plants. In humans, the hypothesis of exposure to ultrasound and subsequent electrolytic balance changes in the nerve tissue and increased blood glucose levels were reported. The power of ultrasound in destroying microorganisms has attracted the attention of many scientists. In studies, it was found that the thermal effect of ultrasound wounds caused bacterial colony damage and It was also argued that exposure to ultrasound even for a short time leads to the thinning of the cell wall and the release of the cytoplasmic membrane and the removal of membrane from the cell wall. Mechanical effects of this type can be used for water and wastewater disinfection [13, 14].
There are several standards that define the limits for exposure to ultrasound waves, which is different from country to country. Table 1 shows the list of exposure limitations for ultrasound radiation, according to the US Occupational Health and Safety Administration (OSHA) [15].

Table 1- Limitations of Ultrasound Exposure by the US OSHA [15]

	Measured in Air in dB re 20μPa Head in Air		Measured in Water in dB re 1μPa Head in Water
Mid-Frequency of Third-Octave Band (kHz)	Ceiling Values	8-Hour TWA	Ceiling Values
10	105	88	167
12.5	105	89	167
16	105	92	167
20	105	94	167
25	110		172
31.5	115		177
40	115		177
50	115		177
63	115		177
80	115		177
100	115		177

MATERIAL AND METHODS

This research is a descriptive-analytic study that was carried out in a batch experiment on raw samples that were taken from sewage treatment plant of South Tehran. Table 2 shows the properties of raw sludge.

Table 2 - Specifications of raw sludge samples

Temp	pH	E-Coli	Parameter
°C	-	MPN/100 ml	Unit
22 ± 1	7.88 ± 0.1	3.24×10^8	Amount

The ultrasonic apparatus used in this study was the Sonics Vibra Cell with a maximum output power of 750 W and a steady-state navigation frequency of 20 kHz. The components of the system used in this study are shown in Figure 3. All microbial tests using MPN method were performed in several stages of probabilistic, confirmatory and complementary studies using 15 tubes and the unit was reported as MPN in 100 ml. These experiments were carried out at the Nanotechnology Laboratory, Water and Wastewater Department of the University of Tehran, and based on the test No. 9221 of the Standard Methods for the Examination of Water and Wastewater [16].

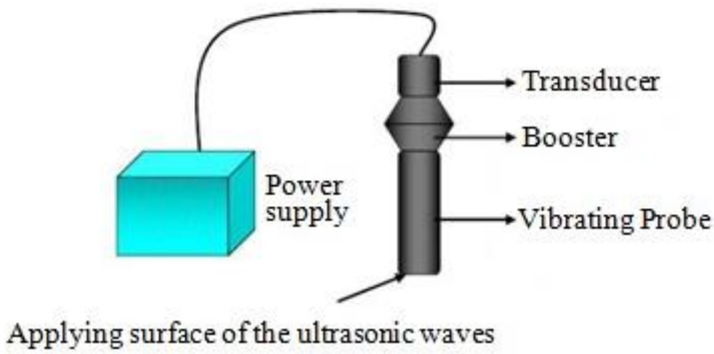

Figure 3. The ultrasonic system components used in this research

RESULTS AND DISCUSSION

Changes in Escherichia coli population by considering the different ultrasound densities are shown in Figure 4. This graph shows a decrease in the population of the Escherichia coli exposed to sonication by increasing the density of the ultrasound from 0.375 to 2.5 watts per milliliter which in this value, and according to Figure 4, the optimal removal rate of 99.43%, which is equal to 2 log reduction, was obtained. Also, with an increase in the density of ultrasound from 1.3 to 2.5 watts per ml, less than one percent increase in removal was observed, therefore, tests for more ultrasound density stopped at this rate. Gholami and colleagues conducted parallel experiments to deactivate and remove E.coli by applying ultrasonic waves. It was observed that when the frequency of ultrasonic waves was 20 kHz, with the increase in the time of sonification, the percentage of removal increased and reached a maximum of 99% at the maximum research time of 9 minutes, which results in a similar trend to the present research [17].

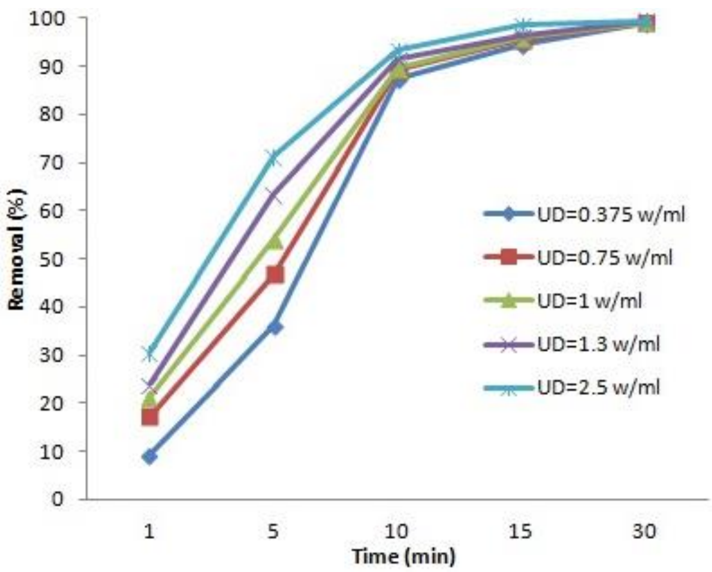

Figure 4. Changes in Escherichia coli population by considering the different ultrasound densities

CONCLUSION

Among the studies on the physical, chemical and biological effects of ultrasound waves on plants, it was observed that ultrasound radiation resulted in the rotational movement of the protoplasm in individual

cells and affects the growth rate of plants. In humans, the hypothesis is that exposure to ultrasound and subsequent electrolytic balance changes in the nerve tissue and increased blood glucose levels.
Ultrasonic waves disrupt the pathogenic colonies and destroys the cell walls of pathogens, viruses and germs. On the other hand, the high temperature caused by the cavitation phenomenon can also locally kill the pathogens. High hydrodynamic forces and high localized temperature appear to be the most important mechanisms for the process of disinfection due to the application of ultrasonic waves.
According to the results of this study, the maximum removal rate of Escherichia coli was 99.43% for optimal conditions in ultrasound density, sonication time and ultrasonic wave frequency of 2.5 kilowatt per liter, 30 minutes and 20 kHz respectively. The research has shown that the use of ultrasonic waves significantly achieves two objectives of stabilization and disinfection.

CONFLICT OF INTEREST

The author declares no conflicts of interest in this paper.

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