

THE USE OF ULTRASOUND IN THE TREATMENT PROCESS OF WASTEWATER. A REVIEW

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ABSTRACT

In this paper, different types of ultrasound devices for the treatment process of wastewater are presented. The use of ultrasound in treatment processes is a method of perspective, an alternative to conventional methods. This technique is based on the cavitation phenomenon that occurs in liquids at ultrasonic irradiation and it is used to enhance or ensure the processes of heat and mass transfer. Some of the main advantages of using ultrasound, namely low consumption of additional material or energy, are presented in this paper. The categories of the ultrasonic transmitters distinguished on the basis of the principle underlying the generation of acoustic waves are described.

KEYWORDS: ultrasound, ultrasonic frequency, cavitation, wastewater treatment

1. Introduction

Ultrasound has proved to be effective in many processes common in the chemical industry, to improve dewatering and drying materials, to enhance filtration, to assist heat transfer, to degas liquids, to accelerate extraction processes, to degrade chemical contaminants in water and to enhance processes where diffusion takes place [1]. The reason why ultrasound power can produce chemical and physical effects is the phenomenon of acoustic cavitation [2]. In most liquids, cavitation is initiated by the excitation of preexisting microbubbles or other inhomogeneities in the fluid such as suspended particles or gas bubble nuclei [3]. Acoustic cavitation involves the formation and subsequent collapse of micro-bubbles from the acoustical wave induced compression / rarefaction [4].

The main driving mechanism in the degradation of pollutants using cavitation is the generation and subsequent attack of the free radicals though some of the reactions have been explained more suitably on the basis of hot-spot theory (localized generation of extreme conditions of temperature and pressure) [5].

Upon collapsing, each of the bubble would act as a hotspot, generating an unusual mechanism for high-energy chemical reactions to increase the temperature and pressure up to 5000 K and 500 atm, respectively, and cooling rate as fast as 10^9 K/s (Figure 1) [7, 8]. There are three potential reaction zones in sonochemistry [9, 10] i.e. inside the cavitation bubble, interfacial liquid region between cavitation bubbles and bulk liquid, and in the bulk solution.

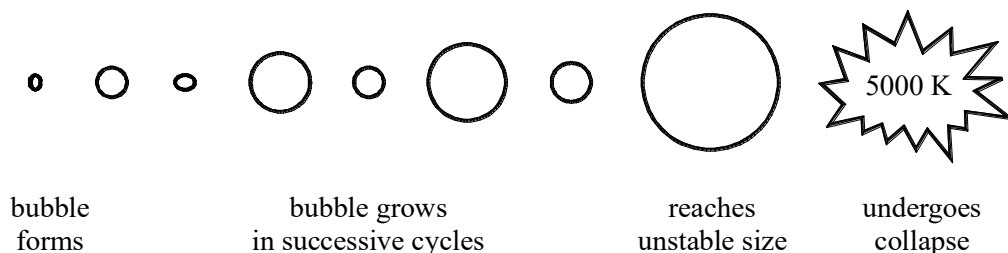


Fig. 1. Cavitation bubble formation, growth and collapse [6]

A representation of the pilot-scale pieces of equipment based on acoustic cavitations is shown in Figure 2 [11]. According to Gogate *et al.* (2004), the pieces of equipment with higher dissipation area give larger energy efficiency at similar levels of the

supplied input energy. Also, the use of the equipment based on multiple frequencies (multiple transducers) has been reported to be more beneficial as compared to the equipment based on a single frequency [11].

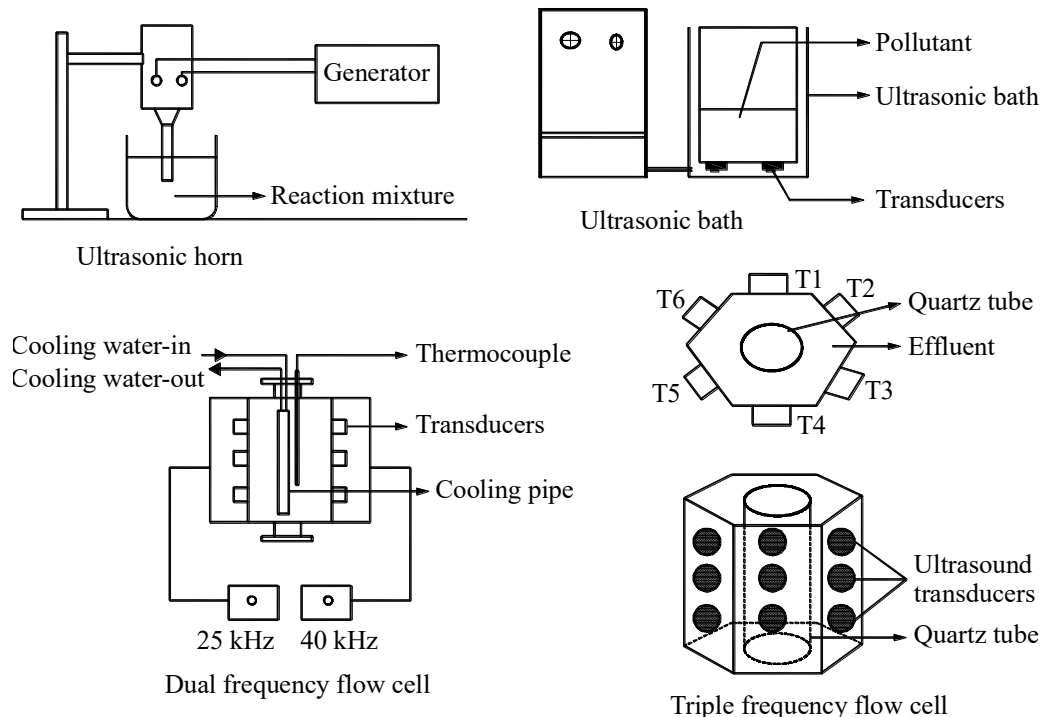


Fig. 2. Schematic representation of the pieces of equipment based on acoustic cavitations [11]

Nowadays, there are numerous constructive types of acoustic emitters, used in the treatment process of wastewater. The most often used emitters are the electromechanical ultrasound generators, relying on piezoelectricity [12-15] and magnetostriction phenomena [16-19]. There are also several applications of sonic mechanical generators [20-26]. Therefore, in this brief review some experimental achievements pertaining to the use of different ultrasonic generators for the treatment process of wastewater are presented.

2. Wastewater treatment by piezoelectric generators

The basis for the present-day generation of ultrasound was established as far back as 1880 with the discovery of the piezoelectric effect by the Curies [27, 28].

Certain materials will generate an electric charge when subjected to a mechanical stress, and change their dimensions when an electric field is applied across the materials. These are known respectively as the direct and the inverse piezoelectric effect [29]. The effect is observed in a variety of

materials, such as quartz, dry bone, polyvinylidene fluoride [30].

The ultrasonic transducers based on the inverse piezoelectric effect rely on some materials response to the application of an electrical potential across opposite faces, with a small change in dimensions [28]. The operation of the piezoelectric generator is based on the usual property of a quartz crystal to deform in the electric field.

The transducer, typically an assembly comprised of a series of aluminum blocks or discs and electrically active piezoelectric elements in a "sandwich" configuration, acts as a mechanical transformer and "rings" much like a bell at its resonant frequency when suitably excited by the driving piezoelectric element [31]. The schematic representation of this type of transducer is shown in Figure 3, where: 1 - screw or pin settings (gripping) to transmitter; 2, 5 - blocks of metal (eg. aluminum, iron, brass); 3, 4 - piezoelectric ceramic plates (cylindrical, annular).

Considering that sonochemistry occurs in the close vicinity of the ultrasonic transducer, where the acoustic cavitation activity is relatively high [33], most applications of ultrasound are performed at

laboratory scale [34] by the use of ultrasonic transducers based on the inverse piezoelectric effect. From the reverse piezoelectric effect, the conversion of electrical to mechanical energy is carried out by the ultrasonic transducer, enabling the formation, growth and collapse of transitory cavitation bubbles in the sonified liquid [8, 35]. Important physical properties of a piezoelectric ceramic used as a driver for high amplitude oscillations are (1) a high Curie temperature, (2) a low dissipation factor, and (3) a high "d" constant. Low losses result in less heating of the ceramic, thus prolonging its lifetime of operation. The "d" constant is the ratio of the mechanical strain produced from an applied electromagnetic field [36].

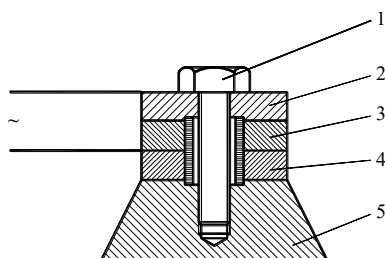


Fig. 3. Construction of sandwich type piezoelectric ceramic transducer [32]

The spreading area of the cavitation influence (the zone of developed cavitation) is limited by the damping of spread vibrations in viscous liquids or the change of wave resistance in cavitating liquid (practically up to the wave resistance in gas media). It limits the output of ultrasonic vibration energy from irradiator [14].

Some of the numerous experimental achievements using piezoelectric transducers are shown below. It should be noted that the majority of the work using this type of transducers is at a laboratory scale. Wenjun *et al.* [4] proposed a facility with ultrasonic transducer based on the piezoelectric effect. Experiments have allowed the removal of ammonia nitrogen and of two other organic pollutants (hydrazine and urea) from the simulated ammonia wastewater, up to 90%. The treatment conditions varied depending on the treatment type (intermittent or continuous), the pH variation and the treatment time. Matouq *et al.* used a piezoelectric transducer to remove pesticides from simulated wastewater. The experiment succeeded in removing the contaminant in a 70% ratio [37]. In paper [38], ultrasonic irradiation was carried out with a high-intensity ultrasonic probe system to remove chlorpyrifos and diazinon from the aqueous solution. The two pesticides were removed for up to 55%. Young K. studied the decomposition of monochlorophenols in paper [39] by sonication of 550 W output power and 20 kHz frequency. After 6

hours of reaction time, more than 80% of monochlorophenols were decomposed for experiments conducted in aqueous solution of pH 3 [39]. There should also be noted the promising results obtained for the formic acid degradation process using ultrasound proposed by [40]. The optimal operating volume was set at 300 ml, at different initial concentrations and using additional mechanical agitation, with a 40 W constant supplied power and 590 kHz constant frequency of irradiation.

3. Wastewater treatment by magnetostrictive generators

The operation of the magnetostrictive generator is based on the fact that some ferromagnetic substances change size at magnetization. If these substances are disposed in an alternating magnetic field, they will start to oscillate, in which case they can become sources of ultrasound. Like the piezoelectric generator, oscillating plates sizes need to be chosen so that their own frequency coincides with the frequency of the excitation (electric or magnetic frequency field), since they work in resonant mode. Magnetostriction occurs in most ferromagnetic materials, but among them the rare-earth alloy Terfenol-D ($Tb_{0.3}Dy_{0.7}Fe_{1.9}$) presents, at room temperature, the best compromise between a large magnetostrain and a low magnetic field [41]. Figure 4 shows the cross section of a prototypical Terfenol-D magnetostrictive transducer, in which the generated strains and forces are sufficiently large to prove advantageous in transducer design [42].

For magnetostrictive materials, due to the magnetomechanical effect, the change in magnetization along the stress direction can be produced by the stress, leading to the conversion of the mechanical energy into electrical energy [17, 43].

Magnetostrictive transducers are inherently more rugged [44] and better suited for industrial use [19].

The highest reasonable frequency achievable in a magnetostrictive transducer is around 30 kHz [45]. Magnetostrictive systems rely on the double conversion of electrical to magnetic energy and then from magnetic to mechanical to produce the sound wave. Magnetic systems are usually less than 50% efficient due to the energy lost in the heating of the coils and the effects of magnetic hysteresis. Additionally, the generators, even if well-tuned, are generally no more than 70% efficient [46].

Thoma *et al.* used a magnetostrictive system to degrade both benzene and toluene in a continuous stirred tank reactor [19]. They obtained good decontamination results by the use of 22-liter reaction vessel consisting of opposing diaphragm plates operating at 16 kHz and 20 kHz [19].

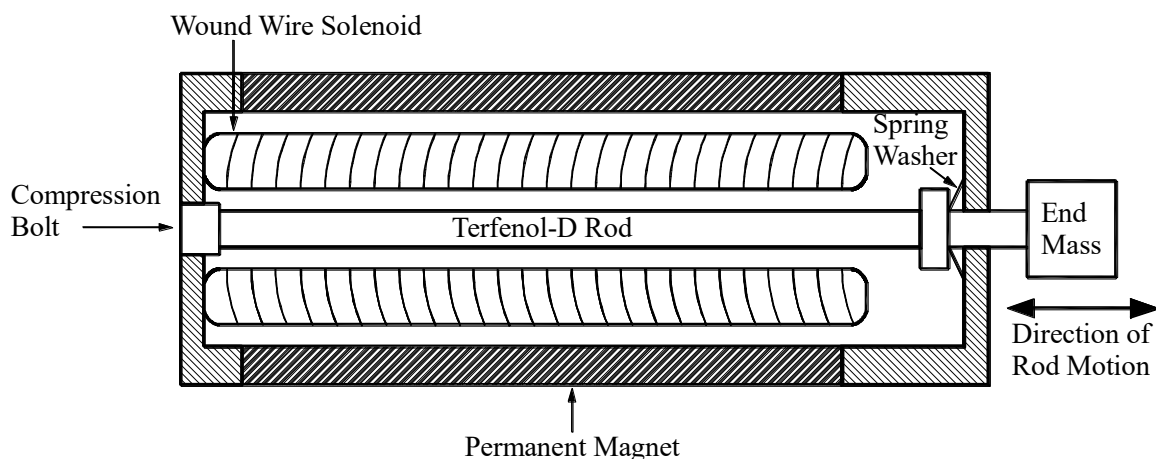


Fig. 4. Cross section of a prototypical Terfenol-D magnetostrictive transducer [42]

4. Wastewater treatment by mechanical generators

Mechanical transducers can be both gas driven and liquid driven [6]. The mechanical air-jet generator was proposed by Hartmann in order to treat liquids both by means of ultrasonic and bubbling [47]. The air-jet generators are mechanical devices with no moving parts that generate ultrasonic pressure waves with low frequency ($10\div 30$ kHz), based on the nonstationary phenomena [48] occurring in the flow of high-speed jets of gas. The technological process of aeration / bubbling serves to enhance the diffusion of oxygen into the water. Figure 5 shows one of the many construction schemes of this type of generators, where: 1 - nozzle; 2 - resonator; 3 - stem; 4 - the jet first cavitation nucleus; 5 - acoustic oscillations of the generator; φ_a - nozzle edge angle; ψ_R - resonator edge angle.

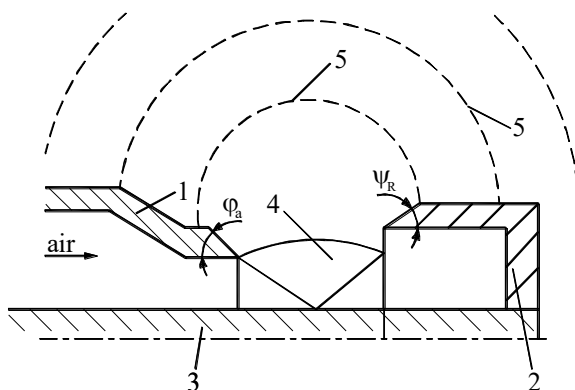


Fig. 5. Oscillations occurrence in the sonic generator [49]

The sonic gasodynamic generator proved to be a solution in water purification technology arising from

aquaculture [50, 51], and also in some applications of liquids from food industry [52, 53].

In paper [54] the used axial sonic air-jet revealed a complete turbidity reduction from wastewater, after 40 seconds of treatment, with 40 NTU initial concentration. Paper [55] shows the reduction of ammonia concentration from industrial ammonia water, using the air-jet generator calculated by the method [56].

Conclusions

Sonochemical degradation seems to be a promising technology for the degradation of several organic compounds.

The present study shows the operational possibilities of the two types of existing ultrasonic transducers, namely mechanical and electromechanical (piezoelectric and magnetostrictive) transducers.

Piezoelectric transducers utilize the piezoelectric property of a material to convert electrical energy directly into mechanical energy. Magnetostrictive transducers utilize the magnetostrictive property of a material to convert the energy in a magnetic field into mechanical energy. Mechanical transducers utilize mainly the air as working agent to produce both low frequency ultrasound and bubbling.

All constructed types of ultrasonic transducers have promising results, but due to the large range of frequencies and power supply, the piezoelectric ones are the most commonly used.

It should be noted that the ultrasonic technology, regardless of the type of transducer, is generally used at laboratory scale, the magnetostrictive transducer being the best suited for industrial use.

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