

# Effects of Ultrasonic Treatment on the Waste Activated Sludge

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**Abstract** –Many of the organic compounds make up much of the sludge mass in particulate form and thus require hydrolysis, which is a rather slow process. In order to improve the hydrolysis, some other physical and chemical pre-techniques such as thermal hydrolysis, mechanical disintegration, ultrasonic irradiation (ultrasonication), ozone treatment, acidification, and alkaline supplement are applied. Two of these techniques, those are ozone treatment and ultrasonication are generally regarded as environmentally non-hazardous. This preference of ultrasonication is based on the view that this method, as a speed fixing instrument, reduces the time limit of hydrolysis from 20 to 8 days; improves the quality and quantity of the biogas as an end-product; helps microbiological cells break into intracellular entities. The current studies have proved a lengthy ultrasonication period, a low-frequency ultrasonic wave and a high ultrasonic intensity are highly effective for the sludge disintegration. The aim of this work was to review the current studies on the issue mentioned above and presented a brief summary of the results.

**Keywords**–Cavitation, disintegration, sludge treatment, ultrasound, wastewater treatment

## Ultrasonik Arıtmanın Atık Aktif Çamur Üzerine Etkileri

**Özet** –Aktif çamur içerisindeki birçok organik bileşik partiküler formda bulunmakta olup, yavaş bir süreç olan hidroliz işlemiyle ayrışmaktadır. Bu süreci hızlandırmak için ısı hidroliz, mekanik bozunma, ultrasonik radyasyon (ultrasonikasyon), ozonla arıtımı ile ortama ilave asit ve alkali kimyasalların eklenmesi gibi fiziksel ve kimyasal ön işlemler uygulanabilmektedir. Bahsedilen yöntemler içerisinde ozonla arıtım ve ultrasonikasyon işlemleri çevresel açıdan zararsız olmaları dolayısıyla tercih edilmektedir. Bu bakımdan ultrasonikasyon işlemi, gerekli ekipmanın hızlı kurulumu ile hidroliz süresini 20 günden 8 güne kadar indirebilmesi, biyogaz kalite ve miktarını artırıcı etki göstermesi ve mikrobiyal bozunmadaki etkinliği gibi nedenlerden ötürü dikkat çekici bulunmuştur. Günümüzdeki çalışmalar uzun süreli ve düşük frekanslı ultrasonik uygulamaların çamur bozundurulmasında oldukça etkili olduğunu göstermektedir. Bu çalışmanın amacı, yukarıda belirtilen konulara ait yapılmış çalışmalarını inceleyerek, sonuçlarını özet olarak sunmaktır.

**Anahtar Kelimeler**–Kavitasyon, bozunma, çamur arıtımı, ultrason, atıksu arıtımı

### 1. INTRODUCTION

The biological wastewater treatment process results in a great amount of waste activated sludge (WAS). Approximately 40 to 60% of the cost of all treatment period comes from the procedures related to the treatment and disposal of sludge [1]. Anaerobic digestion is a slow process and generally used for sewage sludge stabilization, minimization and production of biogas. Anaerobic degradation of particulate material and macromolecules is considered to follow of four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis [2]. In the case of sewage sludge digestion, the biological hydrolysis has been identified as the rate-limiting step [3]. In order to

improve the hydrolysis, some other physical and chemical pre-techniques such as thermal hydrolysis, mechanical disintegration, ultrasonic irradiation (ultrasonication), ozone treatment, acidification and alkaline supplement are applied [4-9]. This preference of ultrasonication is based on the view that this method, as a speed fixing instrument, reduces the time limit of hydrolysis from 20 to 8 days; improves the quality and quantity of the biogas as an end-product, regard as non-hazardous to the environment and helps microbiological cells break into intracellular entities [4-10].

Ultrasonic disintegration is a well-known method for the break-up of microbial cells to extract intracellular

material [2]. Ultrasound is a pressure wave that propagates a vast amount of energy dissipation. Gas and vapor bubbles are generated grow and collapse violently at high velocity and this is called “acoustic cavitation” [10,11]. Cavitation occurs at a frequency of 20-40 kHz. Cavitation is the phenomenon where microbubbles are formed in the aqueous phase and expand to an unstable size and then rapidly collapse. The sudden and violent collapse of huge numbers of microbubbles generates powerful hydromechanical shear forces in the bulk liquid surrounding the bubbles [8]. Macromolecules with a molar mass above 40.000 are disrupting by the hydromechanical shear forces produced by ultrasonic cavitation. The mechanical forces are most effective at frequencies below 100 kHz [12].

The collapsing of the bubbles often results in localized temperatures up to 5000 K and pressure up to 180 MPa [13]. In these extreme conditions induce many physical and chemical effects. Water also undergoes thermolysis in the bubbles to release radical species (H·, OH· and HOO·) which react with the substances in water [14,15]. The current studies have proved a low-frequency ultrasonic wave and high ultrasonic intensity are highly effective for sludge floc disintegration and cell lysis.

Cavitation bubble collapse occurs when the expanding bubbles have reached their resonant radius. The resonant cavitation bubble radius is a function of the ultrasound frequency and calculated with the below equation (Eq. 1) for pure water;

$$\rho \omega_r^2 R_r^2 = 3 \gamma P_o \quad (1)$$

$\rho$  = density of water (kg/m<sup>3</sup>)

$P_o$  = pressure exerted on the liquid (atm)

$\omega_r$  = resonance angular frequency (  $2\pi f$  )

$\gamma$  = ratio of the specific heats of gases

$R_r$  = resonant bubble radius (mm)

$\gamma$  correlates to the heat released upon gas compression and varies from 1.66 to 1.4 and 1.33 for monoatomic, diatomic and triatomic gases, respectively [16,17]. Taking the case of air bubbles in water at atmospheric pressure, the ultrasonic cavitation bubble radius can be approximated as defined in Eq. 2 that is valid for pure water and low surface tension.

$$f_r R_r \approx 3.28 \quad (2)$$

$f_r$  = resonance frequency (kHz)

The bubble radius is inversely proportional to the ultrasound frequency. The application of low frequencies creates larger cavitation bubbles [2].

The important parameters which effect the ultrasonic disintegration of sludge are; power input, total solid (TS) content, sonication time and volume of sludge. The specific energy ( $E_s$ ) was defined (Eq. 3) as the product of the ultrasonic power and time divided by the sample volume and the initial concentration of total solids.

$$E_s = \frac{P \cdot t}{V \cdot TS} \quad (3)$$

$P$  = power input (W)

$t$  = sonication time (s)

$V$  = volume of sludge (L)

$TS$  = total solids content of sludge (mg/L)

Researches on ultrasonic pre-treatment or disintegration of sludge have been on a steady rise for the last ten years. The aim of this work was to review the current studies on the issue mentioned above and presented a brief summary of the results.

## 2. DISINTEGRATION OF WASTE ACTIVATED SLUDGE

Feng et al. [18] was performed settling velocity (ST), total solids (TS), volatile solids (VS), dissolved solids (DS) and the size distribution analysis in the sludge samples which exposed and not exposed to sonication. During these experiments, applied ultrasound energy was varied between 0 and 26.000 kJ/kg TS. The sludge samples were centrifuged at 25°C in 30 minutes at 4000 rpm and the ammonium nitrogen (NH<sub>4</sub>-N), nitrate nitrogen (NO<sub>3</sub>-N) and EPS contents were determined on the supernatants. Furthermore, microscopic experiments were performed on the sludge flocs in terms of observing the changes after ultrasonic irradiation. The results were summarized below:

- A comparison of the settling velocity (SV) of treated and untreated sludge samples is shown in Fig. 1. SV values increased after the first hour, but then decreased thereafter. Between 4<sup>th</sup> and 8<sup>th</sup> h, the SV of the treated sludge was nearly identical to that of the untreated sludge.

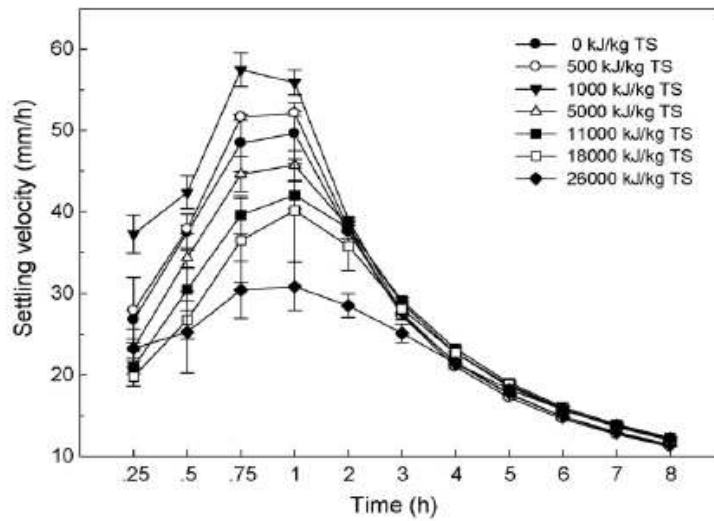


Figure 1. Effect of ultrasonic energy on sludge settling velocity [18]

- Ultrasound treatments with high specific energies (>5000 kJ/kg TS) failed to improve the sludge settleability.
- The turbidity of the supernatant of treated sludge was increased for  $E_s$  dosages >5000

kJ/kg TS (Fig. 2). This was most likely attributable to increases in the amount of micro-particles released from sludge flocs into the supernatant at high-energy doses, because high-energy ultrasound was extremely effective at producing smaller particles (Fig. 3).

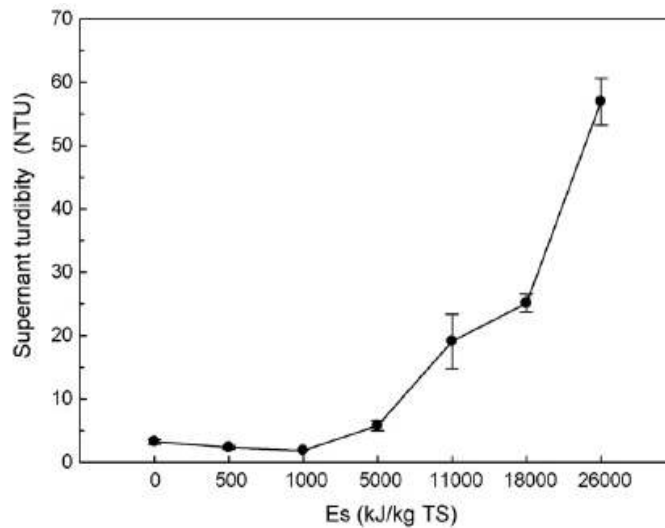


Figure 2. Effect of ultrasonic energy on sludge supernatant turbidity [18]

Treatment with energy dosages below 1000 kJ/kg TS barely managed to disrupt floc structure and therefore did not release large amounts of organic matter as micro-particles into the supernatant. Thus, this finding and the results of similar studies [4,19,20] suggested that 1000 kJ/kg TS was the minimum energy required to disintegrate sludge under these experimental conditions:

- Ultrasonication greatly facilitated mass transfer from the solid phase into the aqueous phase. Nevertheless, disintegration was not complete, even at a dosage of 26,000 kJ/kg TS.
- Microscopic sludge structures were enlarged 100 times to observe disintegration of floc structures. It was

reported that either the floc structure or the microbial cells were totally disintegrated, even at energy dosages as high as 26,000 kJ/kg TS, because a network of

filamentous bacteria was still observed in the microscopic observations on sonicated sludge.

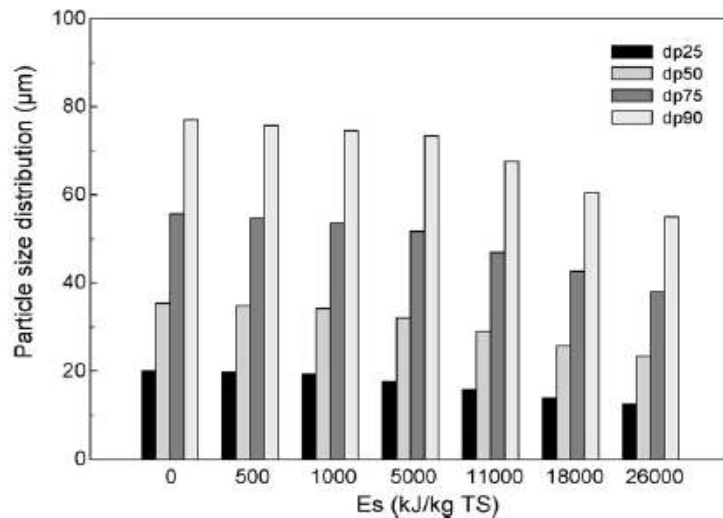


Figure 3. Effect of ultrasonic energy on the particle size distribution of sludge [18]

- Ultrasonication process provided the destruction of floc structures and accordingly cell walls. As a result of this, increasing of soluble chemical oxygen demand (SCOD), extracellular polymeric substances (EPS) and inorganic nitrogen content have been observed in a similar studies [10,18,20-23].

### 3. CONCLUSION

The main objective of this work was to review the current studies on the ultrasonic treatment of waste activated sludge and present a brief summary of the results. The current studies have proved a lengthy ultrasonication period, a low-frequency ultrasonic wave and a high ultrasonic intensity are highly effective for the sludge disintegration. During the sonication period of the experiments, observations have been made on the differentiation of the soluble chemical oxygen demand (SCOD), concentration of supernatant nucleic acid and protein, biological activation of the sludge and the solid content. Ultrasonication process provided the destruction of floc structures and accordingly cell walls. As a result of this, increasing of soluble chemical oxygen demand (SCOD), extracellular polymeric substances (EPS) and inorganic nitrogen content have been observed.

Ultrasound simultaneously caused acoustic cavitation, agitation, and local heating, but the predominance of each phenomenon differed during each stage. Thus, the physical-chemical characteristics are need to be described in terms of reflecting different changes at different stages of the sonication of WAS.

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