Relationship between the effect of intermittent ultra-sonication and specific energy on degree of disintegration of secondary sludge

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Received: April 7, 2018 Accepted: September 6, 2018

Expended Abstract

Introduction

Disintegration of excess sludge from activated sludge units for production of a carbon source in post-anoxic processes in order to remove nutrients from wastewater streams has been widely used in recent years. For this purpose, ultra-sonication is one of the most applicable methods for disintegration of cell membranes to provide carbon, the source from disruption of microorganisms. Such substances extracted from disintegrated sludge can be used as readily bio-degradable sources of carbon to be used by other microorganisms in following process units. The amount of power (P) per volume (V) applied to the samples in specific durations (t) as well as the concentration of sludge is the most dominant factors in determination of the disintegration process. The main hypothesis of this research is that if the sonication of samples is intermittent during the total time of ultrasonic radiation, the defensive mechanism of cells will be weakened due to irregular forces applied to the cell membrane. This will lead to degradation of microorganisms at lower Specific Energy (Es) while the energy consumption in the whole process will be reduced accordingly. The effect of this parameter has been investigated through this research, whilst no research has been focused upon this issue earlier in previous studies. In this research, samples of secondary sludge have been disintegrated at the frequency of 24 kHz while the applied power, time of sonication and sludge concentration were changed for each set of experiment. As an extra independent variable, intermittent sonication was altered from 0.3 to 0.9 second. Degree of Disintegration (DD) was monitored as a dependent variable to evaluate the efficiency of the sludge disintegration process.

Materials and Methods

The sludge for disintegration was sampled at the outlet of an anaerobic tank fed by a continuous stream of wastewater. Prior to anaerobic phase, the sludge was aerated in an aerobic tank at a retention time of 12 hours. Raw wastewater with the average COD content of 358 mg/lit was daily supplied from a municipal wastewater treatment plant named Mahalati and located at north-east of Tehran, Iran. The type ultrasonic set was Sonotrode with a 5 mm diameter probe manufactured by FAPAN (Iran). The generated frequency and maximum power generated by the set were 24 kHz and 300 watt, respectively. The degree of disintegration has been calculated by the method introduced by Muller (2000) and one Molar NaOH was used to determine the total COD of the sludge. To separate the supernatant of the sludge from its solid contents, a centrifuge set (SDN- United Kingdom) was used along with and ultra-filtration by a 0.45 micron glass filter (CHMlab, Spain). For experiment design, a Response Surface Method and Central Composite Design were developed using Design Expert software. The power, sonication duration, solid content of the sludge samples and intermittent sonication were independent variables and degree of disintegration was considered as dependent parameters. For standardizing the independent variables, Specific Energy (Es) was calculated at each stage. Determinations of

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COD and solid concentration were performed in accordance with Standard Methods for Water and Wastewater Experiments. For COD measurement, a colorimetric method was used by Hach DR 1900 (Germany) as Spectrophotometer.

Discussion of Results

Considering aforementioned independent parameters, a relationship between these variables has been proposed as Equation (1). The desirability of the model has been evaluated through ANNOVA variance analyzes for proposed logarithmic model. The R^2 parameter for this model was calculated as 0.9797.

$$\text{Log}_{10}(\text{DDCOD}) = -3.27179 + 1.78725\text{E-}003 \times \text{Watt} + 5.28686 \times \text{Seq} + 0.16406 \times \text{Time} - 0.098290 \times \text{Density} - 3.82414 \times \text{Seq}^2 - 8.14053\text{E-}003 \times \text{Time}^2 \quad (1)$$

Considering response surfaces generated by the software for interactions of parameters and their effects on DD, it was figured out that when the power increases, the DD rises up to the maximum of 38% too (under circumstances of this study). Moreover, decreasing sonication sequence from 1 to 0.6 second, leads to increasing the DD and afterwards, this parameter decreases significantly when sequence reaches to 0.4 second. Emitted energy from the probe of the ultrasound generator produces little bubbles of water due to acoustic cavitation. When such bubbles collapse, some radicals such as OH^-, OOH and H^- are formed, which attack the cells in their vicinity. By increasing the power and sonication time, production of such bubbles increases and consequently, the efficiency of disintegration process significantly improves. Additionally, in higher concentration of sludge solid contents, a portion of applied energy to the aqueous systems transfers to the solids instead of making cavitation. In the other words, parts of ultrasound waves are damped by the microorganisms' body. As a result, the number of collisions between radicals and cells are declined, which leads to decrease in the DD parameter. Hence the more sludge is concentrated the less sludge disintegration occurs.
In order to comprehensive understanding of the parameters, Specific Energy (Es) was calculated and a relationship between Es and intermittent sonication with the degree of disintegration has been developed as Equation (2).

$$\text{DDCOD} = -0.30799 + 8.59092\text{E-}006 \times \text{Es} + 1.21280 \times \text{Seq} - 1.00445 \times \text{Seq}^2 \quad (2)$$

The desirability of the model has been verified by ANNOVA analyzes with a R^2=0.9633. According to the respond surface, increase in Es leads to higher efficiency of sludge disintegration, while reduction of sonication sequences from 1 to 0.5 second, affects the DD parameter in such a way that the maximum DD takes place in sequences between 0.6 to 0.7 second. In such circumstances, it can be argued that little bobbles of acoustic cavitation thoroughly dispersed in the sample during the sonication period. These bubbles cause breaking of sludge flocs at the first stage and collapsing of cell tissues in next step. If the radiation is continuous, the resistance of cell walls is strengthened because of uniform collision of bubbles to biomass and its defensive mechanism toward external forces. Such conditions will lead to decrease in degree of disintegration. On the other hand, if the bubbles are not produced in an extremely short period of time (a portion of a second), cell's discipline of defensive mechanism will be devastated and accordingly, they will be more vulnerable to external forces. This will lead to higher values of sludge disintegration.
Another phenomenon that was observed in experimental phase is that when the specific energy increases the optimum point for intermittent sonication approaches from 0.6 to 0.7 second. The reason is that in higher Es values, applied energy to the sludge is high enough to destroy cell tissue. Thus, as soon as sonication starts, the cell membrane disrupts and the theory of alteration in defensive mechanism of microorganisms takes place in smaller scale.

Conclusion

Through a comprehensive literature review associated with ultrasonic sludge disintegration, it was found that no study puts its emphasis on intermittent sonication and its effects on microorganisms. While it is stated that precise microscopic survey is needed to understand the exact mechanism, which has not been performed in this research, macroscopic observations confirm that intermittent sonication can improve the efficiency of the disintegration process. Accordingly, a hypothesis of destructive resonance in cells' structure due to irregular emission of waves is proposed in this study, which should be verified with other extensive microscopic observations. Assuming this theory, when radiation of waves is cut off for a very short period of time, defensive mechanism of microorganisms suddenly interrupts and the cells show a less resistance against external forces. This will lead to disruption of cells in rather lower energy levels.

Based on this research's findings, it is recommended that intermittent sonication is applied instead of continuous radiation for sludge disintegration. This will lead to much more energy savings due to lower sonication time as well as higher degree of disintegration.

Keywords: degree of disintegration, intermittent sonication, respond surface method, sludge disintegration, specific energy, ultrasonic.