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The Effect of Ultrasonic Irradiation on the Anaerobic Digestion of Activated Sludge

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Abstract: The activated sludge method is under continuous development and improvements. The slow degradation rate of sludge in anaerobic digester is due to the rate limiting step of sludge hydrolysis. This is caused by a low biodegradability of the cell walls and extra cellular biopolymers in sludge. It is important to reduce the amount of sludge produced and to reduce its residual organic content. There is a urgent need for the modification in sludge in anaerobic digester for compact, cost effective and efficient process for water purification system. The review showed that ultrasonic irradiation has improved the process of anaerobic digestion, solubilization, cell disruption of microorganisms, disintegration of bio-solids, the reduction of flock size and reduction in weight and volume of sludge. Thus ultrasound treatment has the potential to improve the anaerobic digestion process and enhance the recovery of valuables. This review paper will discuss the role of ultrasound in all these processes.

Key words: Sono-chemical sludge digestion · Ultrasonic decomposition of organics · Ultrasonic cell disintegration · Disintegration of bio-solids · Reduction in size and weight

INTRODUCTION

The universal increasing environmental vigilance and its successive policies have led to the application of improved technologies in wastewater purification plants. This has resulted in higher wastewater and sludge productions. In Europe, agricultural use of dried sludge (bio-solids) created negative reactions [1]. The activated sludge method is under continuous development and improvements [2]. The activated sludge is composed of water, microorganisms (mainly bacteria), extra-cellular polymer substances and the entrapped impurities. One approach to increase the sludge microbial activity is to change the micro-organisms via gene alteration or species optimization and another approach is to stimulate the biomass via simple physical-chemical methods.

It is well known that low UV irradiation dose can stimulate the growth of bacteria and recently ultrasound has been found to have similar effects [3]. Anaerobic digestion technologies have traditionally been employed to reduce of volume and weight of sludge and produce corresponding amount of biogas [4, 5]. The slow degradation rate of sludge in anaerobic digester is due to the rate limiting step of sludge hydrolysis. This is caused by a low biodegradability of the cell walls and extra cellular biopolymers in sludge. It is important to reduce the amount of sludge produced and to reduce its residual organic content. The methods of improvement of the biodegradability of particular substrate are mainly based on better accessibility of the substrate for microorganisms. Pretreatment of sewage sludge by mechanical, chemical, or thermal disintegration can improve the subsequent anaerobic digestion [6]. The ultrasonic irradiation has improved the process of anaerobic disintegration, solubilization, biological degradation, cell disruption of stabilized sludges, disintegration of bio-solids and the reduction of weight and volume. This review paper will discuss the role of ultrasound in all these processes.

Anaerobic Digestion: Anaerobic digestion of particulate material and macromolecules in sewage sludge is

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considered to follow a sequence of four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The biological hydrolysis has been identified as the rate limiting step. Therefore, the pretreatment of sewage sludge by mechanical, chemical, or thermal disintegration can improve the subsequent anaerobic digestion [10, 11]. Ultrasonic disintegration is a method for the break-up of microbial cells to extract intracellular material [5].The ultrasound waves on a liquid produce cavitations which grow in size before violent collapse in microseconds. The violent collapse produces very powerful hydro mechanical shear forces in the bulk liquid surrounding the bubble. It has been shown that macromolecules with a molar mass above 40,000 are disrupted by the hydro mechanical shear forces produced by ultrasonic cavitation. The mechanical forces are most effective at frequencies below 100 kHz [7]. The temperature and pressure inside the collapsing cavitation bubbles rises up to about 5,000K and several hundred Atmospheres [8, 9]. These extreme conditions can lead to the thermal destruction of compounds present in the cavitation bubbles and to the generation of very reactive hydroxyl radicals [10, 11]. In this way sonochemical reactions can degrade volatile pollutants by pyrolytic processes inside the cavitation bubbles and non-volatile pollutants by hydroxyl radical reactions in the bulk liquid [12]. Thus ultrasonic waves enhance the process of sludge digestion.

Sludge Solublization: Ultrasounds have a remarkable effect on sludge solubilisation and on biogas production during batch anaerobic digestion. The ultrasonic process leads to floc size reduction and cells lyses. It is necessary to supply enough energy in order to lyse cells. That permits the release of organic substances into the liquid phase. After matter is solubilised, this becomes more available for bacteria and increase the biodegradability and biogas production. [13].

Biological Activity: In wastewater purification, biological treatment systems are the most cost efficient processes for reducing dissolved biodegradable organic components. To incorporate a biological process in water treatment system during industrial production, high safety measures, stability of operation and cost efficiency are essential components. Thus there is a potential need for compact, cheaper and efficient process for water purification system such as bioreactors. The ultrasonic treatment in bioreactors is a combination of very complex and dynamic effects which are influenced by many factors including temperature, dissolved gases, suspended particles, structures and metabolism of micro-organisms, etc. It is a surprising phenomenon that ultrasound-activated cultures continue with their higher activity for some hours after irradiation stopped. Perhaps changes in the membrane permeability or enzymatic differences of the organisms are generated. Interestingly, discontinuous ultrasonic treatments are more beneficial for activating fermentation than the continuous exposure. It is suggested that only few steps in intracellular metabolisms (e.g. enzymatic biosynthesis) are supported by ultrasound. The use of low power ultrasound in bioreactors may present a significant improvement in cost reduction in the biotechnology industry especially in process of water treatment plants [14].

Cell Disruption of Stabilized Sludge: Ultrasonic disruption of sludge by the jet streams created by the collapse of the cavitation bubbles is a popular mechanical disruption process in sludge treatment. Disruption of sludge cells enables the release of light organic substances into the sludge water thereby exposing them for further anaerobic digestion. In order to reduce the specific energy input, the total solids content of the stabilized sludge is increased before disruption. Subsequent anaerobic digestion of the ultrasonically disrupted sludge can improve biogas production with reduced sludge quantity that is vital to the economic consideration of the wastewater treatment plants. This process encourages the exploitation of valuable materials and energy from stabilized sewage sludge just before its final disposal [15, 16].

Disintegration of Biosolids: The various methods for the improvements of anaerobic digestion process have been explored extensively. The investigations are concentrated on better sludge hydrolysation by thermal pre-treatment [15, 10, 16]. The recent developments are the use of high acoustic intensities and ultrasonic cavitations for the disintegration of biological cells in sewage sludge by cell disintegration and thus enhancing the higher bioavailability of the sludge. Consequently, the reaction rate of anaerobic sludge degradation is increased and a higher degree of biosolids degradation can be achieved [17].

Reduction of Weight and Volume of Sludge: Biological treatment is the most important technology in wastewater purification in which large amount of excess sludge is generated. The cost of sludge treatment accounts for

30-60% of the operational cost of the whole wastewater treatment plant [18] and presents high technical challenge. Previous researches show that ozone and chlorine gases can effectively dissolve the excess sludge and thereby leads to 60-100% reduction of excess sludge within the process [19, 20, 21]. However, ozonation is a very costly process and chlorination causes the production of toxic chlorinated byproducts and chlorine gas itself imposes risks to the activated sludge system. Effective physical disintegration of sludge can decrease the chemical oxidations process [22, 23]. Powerful ultrasound produce very high temperature (5000 K), pressure (500 bar) and extreme shear forces that mechanically attack sludge flocks which not only decompose organic matter but also improves the sludge dewater-ability [24, 25].

Increase in the Concentration of Micro-organisms: Ultrasonic waves at low frequency and low energy are found to increase the concentration of microorganisms and to enhance the bioreactor performance. Schafer and co-workers found that ultrasonic irradiation at 0.3 W/L and 25 kHz increase the biomass by 230% after 5 h irradiation and increased the microbial activity by 50% after 7 h irradiation. The method is used to enhance the treatment of a synthetic wine wastewater. One persistent problem in above studies is that the energy consumption is very high. The reason is that ultrasound waves are directly applied to the bio-reactor in which majority is water that absorb the sound energy. Therefore, the sound energy used for the bio-mass stimulation is very low. This problem can be solved by evaporating the water content in sludge before ultrasonic irradiations [26-28].

CONCLUSION

Ultrasounds have a remarkable effect on sludge solubilisation, reduction of the sludge volume, increases in biogas production, flock size reduction and cells lyses. Ultrasonic pretreatment enhances the subsequent anaerobic digestion resulting in a better degradation of volatile solids and an increased production of biogas. The use of low power ultrasound in bioreactors may present a significant improvement in cost reduction. Lower ultrasound frequency is more effective than higher sound frequency in stimulating activated sludge. Therefore, ultrasonic pretreatment enhances the subsequent anaerobic digestion resulting in a better sludge digestion and efficient recovery of valuables.

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