APPLICATION OF SEWAGE SLUDGE IN INDUSTRIAL WASTEWATER TREATMENT

EDITED BY MAULIN P. SHAH

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Contents

1

Sludge Conditioning, Activation, and Engineering

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1.1 Introduction

During the wastewater treatment process, sewage sludge is generated in massive amounts. It contains a multitude of toxic substances such as heavy metals, organic contaminants, and pathogens. This sewage sludge has severe negative effects in the environment. The water industry is expecting a wide number of constraints due to stringent regulation [1]. In a wastewater treatment plant (WWTP), the cost of the disposal of sewage sludge alone accounts for about 50% [2]. Thus developing a feasible treatment method for this is crucial for waste management. Some of the conventional techniques usually applied for sludge disposal include: composting, incineration, anaerobic digestion, landfill, and recycling. The definition of sewage sludge is that it is the residue produced from the treatment of wastewater. The sludge is comprised of two fractions which are the primary and secondary sludge. The secondary sludge is generated from the biological treatment system. Chemical sludge results from the treatment of sludge with chemicals [3].

Some of the constituents of sewage sludge are protein, fats, nitrogen, phosphoric acid, calcium oxide, cellulose, magnesium oxide, potash, etc. [4]. Sludge components include the chemicals used for treatment. The biochemical transformation during treatment will produce fulvi and humic acids in them. Usually, the treatment methods for wastewater for generating sludge are mechanical treatment such as sedimentation, or sometimes biological process or clarifiers for removal of secondary sludge. The secondary sludge contains harsh chemicals. So, neutralization, coagulation, and precipitation of the above compounds are done. Solids which are removed during mechanical pretreatment are the primary sludge

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which contains a high amount of water, pathogens and they look vile, smell bad and are susceptible, while the secondary sludge is fluffy and yellow in colour, biologically active and dewatering is difficult.

1.2 Conditioning

1.2.1 Conditioning of Sewage Sludge by Increasing the Rate of Hydrolysis

Disintegration is the word for conditioning the sludge by destroying its structure by means of increasing the hydrolysis. Nowadays, more attention is given to the hydrolysis of the sludge. This will in turn increase the biogas production. This biogas can be used as an energy source. Additionally, simultaneous generation of volatile acids during conditioning can be seen. This volatile acid becomes a good carbon source for denitrifiers. The main goal of this type of conditioning is to make the available nutrients accessible to the microbes by disruption of the EPS matrix and cell wall thus aiding hydrolysis (anaerobic digestion) of complex organic molecules of sludge.

1.2.1.1 Mechanical Pretreatment

1.2.1.1.1 Ultrasonic Pretreatment

During ultra-sonication, periodic waves of compression and rarefaction propagate through the wastewater sludge. Microbubbles generated through ultra-sonication collapse rapidly with a time interval of microseconds inducing cavitation. This sudden violent collapse of microbubbles gives rise to extreme temperature of around 5000 K and pressure of around 500 bars. This cavitation generates robust hydro-mechanical shear forces and highly reactive radicals (H · and · OH). The oxidizing effect of reactive radicals and hydro-mechanical shear forces disintegrates the sludge flocs and releases the cellular material [5–7]. The specific energy output of ultra-sonication is optimized based on the total solid content of the wastewater. The main disadvantage of this method is high energy consumption. Specific energy input determines the solubilization efficiency of the sludge. The specific energy input for disintegration of sludge flocs is around 80 KJ L^{-1} [8]. The optimal specific energy input based on total solids was around 1000 KJ Kg^{-1} improves settleability. But for sludge destruction and transformation of insoluble organics into soluble organics, a specific energy input of around 26 000 KJ kg^{-1} of total solids is needed [9]. But this consumes an enormous amount of energy. Ultra-sonication greatly improves the efficiency of anaerobic digestion of sludge. This in turn increases the biogas production (methane). The ultrasound pretreatment method increases the destruction of volatile solids and biogas production by 15–35% [10].

1.2.1.1.2 Microwave Irradiation

Microwave irradiation works in the wavelengths between 1 mm to 1 m and oscillation frequencies in the range 0.3–300 GHz [5, 11]. In theory the damage of sludge flocs can be done in two ways. The first is that dipole rotation under oscillating electromagnetic field generates heat which boils the intracellular fluid and breaks the bacterial cells, and the second way is that changes in dipole orientation of polar molecules breaks the hydrogen bonds and denatures the complex biological molecules [12, 13]. This pretreatment method enhances the solubilization of organic matter in the sludge and increases the biogas production by 50% [14]. This pretreatment method causes rapid lysis of cell residue along with simultaneous disruption of extracellular polymeric substances. The non-thermal effect exerted by disorientation of dipoles has a slight effect on the solubilization of organic matter. But, the mesophilic anaerobic biodegradability of the sludge and biogas production is increased [15]. Although it has its advantages, the microwave irradiation treatment method has no discernible effect on hydrolysis but improves dewaterability and destruction of pathogens responsible for anaerobic digestion.

1.2.1.1.3 Electrokinetic Disintegration

This is a high-voltage electric field method also known as pulsed electric field. During the sludge disintegration process, a high voltage field is induced by charges and causes the rapid disruption of sludge flocs, this makes the nutrients in the effluent easily accessible for the microbes responsible for fermentation [16]. It increases the soluble organic matter by 110–460% in comparison to conventional digestion systems. It decreases the size of the digesters size 40%. The ratio of soluble COD to the total COD increased by 4.5 times and biogas production increased by 2.5 times [17, 18]. The main advantage of this treatment method, is that it drastically reduces the amount of sludge without affecting the treatment efficiency.

1.2.1.1.4 High-pressure Homogenization

During homogenization, the generation of extreme pressure gradient, turbulence, and rapid depressurization creates cavitation and in turn produces strong shearing forces. The sudden pressurization and depressurization breaks the sludge flocs releasing intracellular substances. For sludge disintegration or solubilization, the operating pressure was around 20–80 MPa and the number of cycles was around 1 to 4 [19]. In industry, high pressure homogenization is considered over other pretreatment methods. This is due to ease of operation, high energy-efficiency and low capital cost. This method increases the sludge reduction by 23% and biogas production by 30% [20].

1.2.1.2 Thermal Hydrolysis

Usually, thermal hydrolysis is the commercially accepted and well established pretreatment method for sludge dewaterability [21, 22]. But, research is still underway for its ability to improve sludge disintegration (hydrolysis). The efficiency of this treatment method relies on the treatment temperature and time. The solubilization of sludge increases with increase in operating temperature. The carbohydrates and protein are affected more than lipids in thermal hydrolysis. The operating temperature for sludge solubilization, should not exceed 190 °C for maximum efficiency. Further, increase in temperature decreases the efficiency as it affects the anaerobic digestion. The biodegradability is weakened with further increases in temperature because high temperature results in production of recalcitrant compounds, i.e. melanoidins. These molecules are difficult to degrade and in addition to this even inhibit the biodegradability of organic matter [23]. The treatment time has less influence on solubilization of sludge in comparison to treatment temperature. This technique greatly reduces the hydraulic retention time, this in turn reduces the reactor size for anaerobic digestion. This pretreatment method is advantageous as it destroys pathogens, removs odor, reduces sludge volume, improves dewaterability, etc.

1.2.1.3 Chemical Pretreatment

In this method, the microbial cells in the sludge flocs are deformed by chemicals, this favors enzymatic digestion of organic matter in the sludge. Some of the chemical treatment methods employed are as follows.

1.2.1.3.1 Acidic and Alkali Pretreatment

This methods shows great promise due to ease of operation, high methane conversion efficiency, simple operation, and it is inexpensive [24]. In acid hydrolysis, HCl, H_2SO_4, H_3PO_4, and HNO_3 are used in treatment, while for alkali treatment NaOH, KOH, $Ca(OH)_2$, CaO, and ammonia are used. The major benefit of this method is that it can be performed at ambient temperature [2]. The effectiveness of this method relies on the affinity of the organic matter in the sludge to the acid or alkali and also the characteristics of the sludge. Acid treatment is most suitable for hydrolysis of lignocellulosic biomass but has little to no effect on lignin hydrolysis. The theory behind acid treatment is the hydrolysis of hemicellulose liberating monomeric sugars and oligomers from the matrix of cell wall thereby supporting enzymatic digestibility. The drawback of acid treatment is the generation of toxic byproducts such as furfural, hydroymethyl furufural which strongly inhibits fermentative microbes [25]. Other drawbacks include its corrosive nature due to extremely low pH which can affect the reactor and special measures should be taken into account to prevent the above mentioned problem. To overcome this problem, acidic treatment is integrated with thermal treatment.

On the other hand, alkali treatment is best suitable for the breakdown of lignin. The theory behind this treatment is saponification and solvation, which causes depolymerization and breakage of lignin-carbohydrate linkages [26]. It also saponifies the intermolecular ester bonds of xylan hemicellulose, but the degree of solubilizing them is not as great as acid treatment. The additional alkalinity improves the methanogenic activity and stabilizes the process of anaerobic digestion by acting as a buffer system [27]. NaOH is the most effective in enhancing biogas production and increasing the solubilization of the sludge. Although it has its advantages, some of the disadvantages such as NaOH treatment is not compatible with anaerobic digestion. As overloading NaOH blocks the metabolic pathway of anaerobic microbes and decreases the methane productivity. To overcome this problem, alkali treatment is integrated with microwave, ultrasound, and thermal pretreatment systems in order to reduce the alkali consumption and this also increases the methane productivity.

1.2.1.3.2 Ozonation

This is the most widely employed peroxidation process as it disrupts cell membrane and disintegrates the sludge flocs resulting in excessive solubilization of sludge. Ozonation is integrated with anaerobic sludge digestion to bypass hydrolysis and increase methane productivity [28, 29].

The efficiency of sludge solubilization depends on the dosage and amount of ozone introduced in a moderate range [30]. However, ozonation efficiency depends on the reaction kinetics and mass transfer of ozone. The rate of kinetic reaction between sludge mixed liquor and dissolved ozone is average, even though the applied dosage is high [31]. The introduction of a high dosage of ozone can cause complete mineralization of liberated cellular components affecting methane productivity [32]. The main disadvantage of this method is the high capital investment

The microbubble ozonation was introduced to overcome the high capital investment with higher performance. The sludge solubilization was increased from 15–30% to 25–40% with the bubble contactor with ozone doses of 0.06–0.16g O_3 g^{-1} of total solids and ozone utilization also improved from 72 to 99%. In this process, rapid generation of hydroxyl radicals is seen thereby accelerating the solubilization efficiency of sludge [33].

1.2.1.3.3 Fenton Oxidation

This is a catalytic reaction involving reaction between hydrogen peroxide and the catalyst iron ions(Fe^{2+}). The result generates enormous amounts of highly active radicals (·OH). The hydroxyl radicals generated from this reaction have high oxidative potential of + 2.80 V which is greater than the hydroxyl radicals produced from ozonation and hydrogen peroxide alone. These are effective for the disintegration