REVIEW ON THE PRE-TREATMENT METHODS OF WASTE FOR ANAEROBIC DIGESTION.

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Abstract**—**Any kind of waste has become a serious threat to society and the environment. Anaerobic digestion process was used in the past primarily to produce biogas. Nowadays the anaerobic digestion process has been widely used in the waste treatment sector because of its high efficiency, better life cycle, and generation of clean energy as an output. However, a great deal of research currently is concentrating on the improvement and optimization of anaerobic digestion under various conditions. The most common process factors such as temperature, pH, volatile fatty acids, hydraulic retention time (HRT), organic loading rate (OLR), etc. are being studied and reviewed in the last few years. But this paper signifies the importance of different types of pre-treatment methods which is the primary and very important step of the anaerobic digestion process. The quality and the efficiency to produce biogas within the required timeframe is largely depended on the proper choice of pre-treatment method among other process parameters. Without applying the specific pre-treatment method for an explicit type of waste, the whole digestion cycle can go in the wrong direction. This paper aims to review different pre-treatment methods including mechanical, thermal, and chemical methods for diverse types of waste.

Keywords**—**Anaerobic Digestion, Biogas, Pre-Treatment Method, Waste.

I. INTRODUCTION

THE amount of fossil fuels in the globe is getting limited day by day because of excessive exploitation due to the growth of population, urbanization, industrialization, etc. Therefore, in the last few decades, the use of different renewable sources is receiving attention throughout the globe. Solar, wind, geothermal, hydro, biogas, etc. are the most common forms of renewable energy sources. But among all, biogas probably is one of the promising sources of clean energy as this doesn't have to depend entirely on the availability of other natural sources. For example, solar energy requires sunlight, hydro requires a flow of water or height, wind plant needs a windy environment. Whereas biogas production depends on the availability of the waste materials either food waste or sewage sludge waste. Biogas is the most versatile energy as it can be converted to heat and/or electricity. Biogas can also be purified to convert into biomethane. Biomethane is suitable to replace fossil natural gas in many applications like electricity production, transportation fuel, etc. [1].

Food waste or sewage sludge waste from humans or animals are the main components of the biogas production process. Wastewater is the mixture of liquid or water-carried wastes from industrial, commercial, and residential along with surface water, groundwater from rain [2]. Wastewater contains undesirable solid contents including organic, inorganic, or toxic substances along with many microorganisms. Sludge is the composition of poorly biodegradable organic compounds and looks like heavily concentrated biomass due to the involvement of physical-chemical processes in the treatment plant. The organic solids comprise proteins, carbohydrates, fats, and oils [3]. The protein contains about 16% nitrogen, and together with urea are the major sources of nitrogen in wastewater [4]. Sludge is rich in nutrients such as nitrogen, phosphorus, etc., and many other valuable organic matters which are very useful for micros during the anaerobic digestion process. Westerhoff et al. [5] reported that if all the substance in sludge could be recovered, it would be worth about US$13 million annually for a community of 1 million people. The amount of sludge in the world is increasing daily as the population is increasing by around 81 million people per year [6]. Thus it becomes vital to treat this sludge effectively without causing damage to the environment. Many techniques have been used in the past for treating sludge-like composting, pyrolysis and gasification, mono-incineration and co-combustion, hydrothermal methods, etc. But anaerobic digestion (AD) system has been found as one of the most cost-effective and well-implemented technology for waste sludge treatment due to its limited negative environmental impact [7,8]. Anaerobic digestion (AD) is a series of steps where microorganisms break down biodegradable organic materials in a chamber without oxygen to produce biogas and digestate (bio-fertilizer)

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[9]. The performance and the growth of microorganisms are sensitive to several operational parameters like pre-treatment, temperature, pH, carbon/nitrogen ratio (C/N), type of feedstock, organic loading rate (OLR), hydraulic retention time (HRT), etc. [10]. Proper growth of microbes is essential to improve the production of methane. In this paper, the impact of different pre-treatment methods has been reviewed.

II. Anaerobic Digestion

The anaerobic digestion process can be defined as the breakdown of complex organic matter by the microorganism without the presence of oxygen to produce methane, carbon dioxide, lower amounts of ammonia, and hydrogen sulfide along with traces of other gasses, such as N_2, H_2, CO [14]. The whole process is divided into four phases (hydrolysis, acidogenesis, acetogenesis, and methanogenesis). During the hydrolysis process, the larger molecular weight compounds break into lower molecular weight compounds such as amino acids, fatty acids, and simple sugars [15]. Then in the second phase, organic matters convert into volatile fatty acids. Then the acids convert into acetic acid, hydrogen, and carbon dioxide through acetogenic bacteria which are the major compounds for biogas production. The final methanogenesis step produces methane and carbon dioxide by methanogenic bacteria. Figure 1 shows the breakdown of organic material in different stages of the anaerobic digestion process.

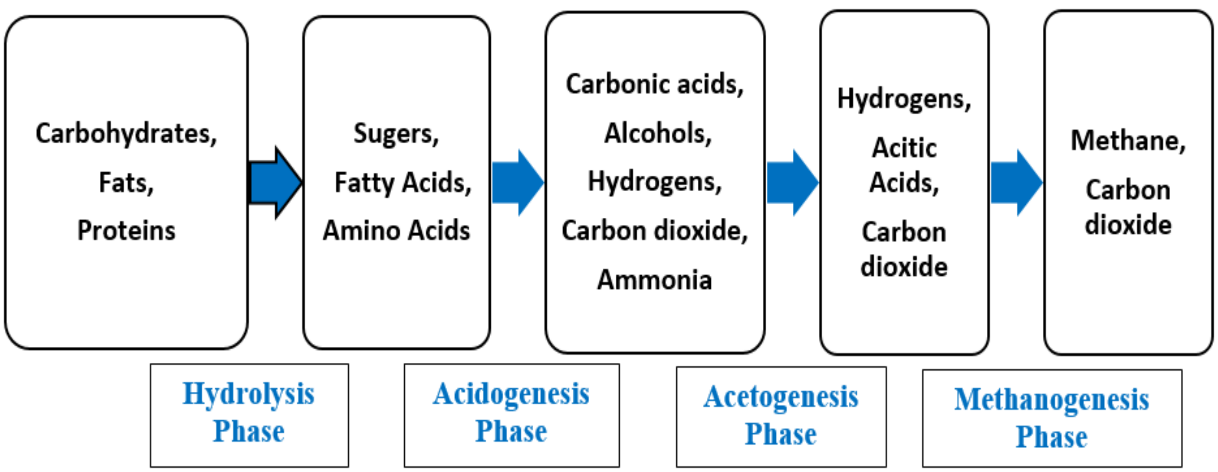

Fig. 1. The key phases of anaerobic digestion [16]

Anaerobic digestion offers huge advantages over aerobic digestion in terms of low energy consumption; reduced solids formation, low nutrient requirements, and better energy recovery. The other alternative treatments like pyrolysis and gasification convert the sludge into fuel whereas incineration and combustion of sludge allow the energy recovery utilizing heat exchangers [11]. All of these sludge treatment methods are much quicker than anaerobic digestion. But they require very a high intensity of energy as input.

III. Pre-Treatments

Municipal Sludge is the composition of both organic and inorganic materials. Hydrolysis is the rate-limiting step in anaerobic treatment [12]. Pre-treatment before AD helps in accelerating the hydrolysis step and increases further biological mineralization of organic compounds which ultimately improves the biogas yield [13]. Anaerobic digestion without any kind of pretreatment takes more time to complete the whole digestion process. Various sludge pre-treatment technologies have been proposed, including mechanical, thermal, and chemical treatments to maximize energy recovery [17]. Different methods of pre-treatment have their advantages and impacts on the sludge. Mechanical pre-treatment is already commercially available and can be used in large-scale plants. Mechanical pre-treatment reduces the particle size resulting in an increase in surface area for the microorganisms that will degrade the organic material [18].

A. *Thermal treatment*

The thermal treatment process directly breaks the big sludge floc, disruption of cell walls, and degradation of extracellular polymeric substances [19]. It also increases the soluble COD (Chemical Oxygen Demand) concentration and improves dewaterability [20]. However, if the temperature goes higher than 175 °C, the biodegradability of sludge decreases [21]. The improved methane yield was obtained with the temperatures range between 160 °C and 180 °C (4.8–12.6 bar) for 30-60 min treatment [22, 23, 12, 24, 25]. But it has been found that thermal hydrolysis with high temperature (170–190°C) produces colored recalcitrant compounds (furfurals and 5-hydroxymethylfurfural, phenolic compounds like ferulic acid, syringaldehyde, and vanillin) which slows down the degradation process [26, 27]. Such a reaction is called the Maillard reaction which involves carbohydrates and amino acids [28]. These browning colored compounds have a negative impact on the whole anaerobic system because it increases the dissolved organic nitrogen and high ultraviolet absorbance (UVA254) capacity recalcitrant compounds having a higher molecular weight than 10 kDa with strong color decreases the ultraviolet transmission as this strong brown color increases absorbance (UVA254) capacity [29, 30]. The production of the recalcitrant compound is temperature-dependent, thermal hydrolysis below 160 °C can reduce the probability of creating such browning compounds [31]. The rate of Maillard reaction increases with the temperature. The soluble COD (Chemical Oxygen Demand) and color increase with the temperature ranging between 140-165 °C [21]. The solubilization level of solids increased linearly with the rise of the temperature in treatment [32]. Bougrier et.al. [33] studied the effect of five different types of sludge taken from different plants in south France to explain the solids solubilization. More than 43% solubilization of organic matter has been observed for treatment over 150°C temperatures.

Thermal treatment at 190 °C was found efficient in terms of COD, carbohydrates, proteins and lipid solubility, and methane production. It has been found that carbohydrates had a degradation yield of 82% at 190 °C thermal treatment compared to just 56% without treatment. The degradation rate for protein is just 46% and 35% with or without treatment at the same temperature range. Among these, the degradation of lipid has shown the better result (84%) with 190 °C thermal pre-treatment whereas 67% without treatment. Above all, the methane yield was increased by 25% with 190 °C treatment [32]. But it is required to find out a favorable temperature for treating sludge where there will be fewer melanoidins formed. An optimum temperature of 140 °C has been found for thermal hydrolysis where no significant negative impact has been noticed in terms of biodegradability of the sludge and solubilization of COD [21]. Table I shows the observations of the AD process after thermal pretreatment at different temperatures.

TABLE I
SUMMARY OF KEY RESEARCH ON ANAEROBIC DIGESTION AND PRE-TREATMENT METHODS

Feedstock/ Input/Fuel Type	Treatment Method	Observation/Outcome	Reference
Waste activated sludge and inoculum sludge	Thermal pre- and inter-stage treatment at moderate temperature: at 80^0 C and high temperature at 130–170^0 C	Total volatile solid increased from 2 to 29% for thermal treatment. TVS increased from 2 to 27% for inter-stage treatment (80^0C). TVS increased from 2 to 25% and 57% at 130 °C and 170 °C respectively with 9% and 29% increase in methane yield.	[34]
Sludge	Thermal pre-treatment at 70^0C temperature	Has a decisive effect on pathogen removal	[35]
Sludge	pre-treatment at 90^0C	Biogas production was improved 20 times when applying a 60 min	[36]

B. Chemical treatment

In chemical treatment, the cell wall and membrane get hydrolyzed which improves the solubility of organic matter (sludge). The most common chemical treatments are alkali pre-treatments (alkaline hydrolysis and alkaline peroxide), pre-treatment with ozone (ozonolysis), acid hydrolysis treatment (H_2SO_4) [37]. The physical and biochemical characteristics of sludge will change with the addition of such chemicals during the pre-treatment step. At first, EPS the extracellular polymeric substances which are located outside the microbial cells gets damaged in the alkaline pretreatment process [38].

EPS include proteins, carbohydrates, humic substances, lipids, and nucleic acids [38]. Sodium hydroxide (NaOH), potassium hydroxide (KOH), lime ($Ca(OH)_2$), aqueous ammonia ($NH_3{\cdot}H_2O$), and hydrogen peroxide (H_2O_2) are reported chemicals that are used in alkaline pre-treatment [39]. Hydroxyl anions destroy the floc structures and cell walls of microorganisms during alkaline treatment. Ionization of hydroxyl groups ($OH^- \rightarrow -O^-$) causes extensive swelling and solubilization of gels in sludge [40]. The destruction of extracellular polymer substances and cell walls results in releasing intracellular substances due to high pH [41]. 63% COD solubilization was achieved and total solids reduction reached 33% with the addition of 21.6g of NaOH/l [42]. Both at ambient and high temperature (140 °C), pre-treatment with NaOH and KOH showed better COD solubilization of 71.6% and 83.7% respectively as compared to the dibasic alkali agents ($Mg(OH)_2$, $Ca(OH)_2$) [42]. The thermal or ultrasonic alkaline process had better results in reducing particle size compared to thermal or ultrasonic-acid pretreatment

[43]. Sulphuric acids (H_2SO_4), hydrochloric acid (HCl), acetic acid (CH_3COOH) are the acid chemicals that are commonly used in acid hydrolysis [44].

C. Ozone treatment

Ozone has been used as part of pretreatment because of its strong oxidative properties. 25% improvement in methane production was achieved by Erden and Filibeli [45] when the secondary sludge had been pre-treated by ozone. During sludge ozonation, ozone decomposes itself into radicals and reacts with soluble and particular fractions, organic or mineral fractions. Ozonation improves the viscosity and settlement of sludge [46]. Compared to raw sludge, ozonated sludge at 0.1 g O_3/g-SS for 5 days showed 2-3 times greater biodegradability [47]. An optimal range for ozone dose has been reported from 0.05 to 0.5 g O_3/g of total solid [48]. The TVS removal efficiency was increased by 35-90% when sludge was pre-treated with ozone [49]. Ozone dose of 0.15 g O_3/g total solids showed an increase in SCOD (Soluble chemical oxygen demand) up to 37% along with improvement in the biogas yield around 2.4 times greater than control [48]. However higher ozone dose can lead to the formation of by-products that are less biodegradable [50]. Higher doses of ozonation (higher than 0.18 g O_3/g TS) can lead to a mineralization phenomenon. Performance decreases with a higher dose probably due to the inappropriate acidic environment inside the digester or the formation of recalcitrant ozonation as by-products [48]. Other downsides of the ozonation process are foaming and poorer filterability of treated sludge [46]. Table II shows the results of the AD process after ozone pre-treatment.

TABLE II
SUMMARY OF KEY RESEARCH ON ANAEROBIC DIGESTION AND PRE-TREATMENT METHODS

Feedstock/ Input/Fuel Type	Reactor Type	Treatment Method	Observation/ Outcome	Reference
Waste activated sludge and inoculum sludge	Batch reactor for 40 days	Thermal pre- and inter-stage treatment at moderate temperature: at 80^0 C and high temperature at $130–170^0$ C	Total volatile solid increased from 2 to 29% for thermal treatment. TVS increased from 2 to 27% for inter-stage treatment (80^0C). TVS increased from 2 to 25% and 57% at 130 C and 170 ^{O}C respectively with a 9% and 29% increase in methane yield.	[34]
Mixed sludge	A semi-continuous reactor at 15–20 days SRT at 37–42^0C	Thermal hydrolysis pre-treatment at $150–170^0$C, 4.8–7.9 bar.	56–62% reduction in volatile solid in digestate. 24–59% increase in biogas production	[25]
Primary, Secondary and mixed sludge	A semi-continuous reactor at 30 days SRT at 35^0C	Thermal pre-treatment using hydrolyser at $134–140^0$C, 3.4 bar for 30 min.	12.6% reduction in volatile solid in digestate. 40.2% increase in methane production	[51]
Dewatered sludge (high solid sludge)	A batch reactor at 28 days SRT at 37^0C	Thermal pre-treatment using low-temperature hydrolysis at $60–90^0$C, for 1–72 h	557–1678% increase in SCOD (Soluble chemical oxygen demand)	[52]

IV. CONCLUSION

The anaerobic digestion process has demonstrated its potential as a technology that not only can reduce the waste amount but also can be used for the production of renewable heat and power and compost. Among all kinds of treatment processes. The thermal treatment process is the most popular method despite having high energy requirements and the potential to produce ammonia and recalcitrant compounds due to overheating. But this process helps to reduce the total volume of waste and reduce the pathogens. On the other hand, despite being expensive and toxic, the chemical process improves the solubility of waste and boosts the methane yield. The combination of two or more types of pretreatment methods still requires much attention despite being costly. Therefore, more study is required to identify the optimized set of parameters for full-scale which could improve the methane production along with the reduction in cost and time.

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