Pretreatment Methods in Anaerobic Digestion for Biogas Generation: A Review

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Abstract - Biogas energy has got importance in the field of energy engineering because of its attractive features. Biogas is produced from different types of waste materials by the process of Anaerobic Digestion. This paper gives the insight of Anaerobic Digestion process and different pretreatment methods used in various experimental research works. Flower waste is also a potential source of biogas energy. In order to carry out biodegradation of flower waste, alkaline chemical pretreatment is essential.

Keywords – Biogas, Anaerobic Digestion, Pretreatment methods, methane yield

I. INTRODUCTION

Energy crisis and ever rising prices of these fuels are major concerns for the society. Hence interest in alternate energy sources is also increasing. Biogas energy is a promising source of energy, as it produces useful energy from waste materials with less environmental emissions.
The method commonly used for biogas production is "Anaerobic Digestion (AD)".
In this method the breakdown of organic compounds takes place in absence of air or oxygen to produce biogas : a mixture primarily containing methane and carbon-di-oxide with small amounts of hydrogen sulphide (H2S) and ammonia (NH3).
Different stages of anaerobic digestion are mentioned below:
1. Stage one Hydrolysis: Large protein macromolecules, fats and carbohydrate polymers (such as cellulose and starch) are broken down through hydrolysis to amino acids, long-chain fatty acids, and sugars.
2. Stage two Acedogenesis: These products are then fermented during acidogenesis to form three, four, and five-carbon volatile fatty acids, such as lactic, butyric, propionic, and valeric acid.
3. Stage three Acetogenesis : In acetogenesis, bacteria consume these fermentation products and generate acetic acid, carbon dioxide, and hydrogen.
4. Stage four Methanogenesis: Finally, methanogenic organisms consume the acetate, hydrogen, and some of the carbon dioxide to produce methane.
Biogas produced would theoretically contain 50 percent methane and 50 percent carbon dioxide. However, acetogenesis typically produces some hydrogen, and for every four moles of hydrogen consumed by hydrogenotrophic methanogens a mole of carbon dioxide is converted to methane. Substrates other than sugar, such as fats and proteins, can yield larger amounts of hydrogen leading to higher typical methane content for these substrates. Furthermore, hydrogen and acetate can be biochemical substrates for a number of other products as well. Therefore, the overall biogas yield and methane content will vary for different substrates, biological consortia and digester conditions. Typically, the methane content of biogas ranges from 40-70 percent (by volume).
Anaerobic Digestion process can occur in Mesophilic temperature range (20OC to 45OC) or in Thermophilic temperature range (50OC to 65OC) or in Psychrophilic temperature range at low temperatures (below 20OC).

II. NECESSITY OF PRE-TREATMENT IN ANAEROBIC DIGESTION

Biogas is produced from various waste materials and energy crops, which can be degraded by microorganisms. The biodegradability of a substrate is important factor which determines the yield of biogas which can be achieved. Starch in organic substrates is almost fully biodegradable while the lignocellulostic materials offer more resistance to anaerobic digestion. The lignin in these materials cannot be degraded by anaerobic bacteria, while most of the cellulose and hemicellulose is often left untreated even after a typical 1 to 2 month digestion process. This can be a major concern, since lignocelluloses rich materials such as wood residuals, paper waste and crop residuals are available in large amounts around the world [15].

A potential solution to this problem is to introduce a pretreatment prior to the biogas production, in order to increase the biodegradability. The goal of a pretreatment is to open up the structure of the substrate, making it less crystalline and therefore more accessible for enzymatic attack. These structural changes will facilitate the adsorption of bacterial enzymes on the cellulose and the hemicellulose, which will further lead to higher production of biogas.

Different pretreatment methods have been developed to increase the degradability of lignocellulose-rich materials. These methods can be divided into mechanical, thermal and chemical (i.e. alkali, acidic, oxidative) as well as biological pretreatments. However, many of these methods require high-energy input, such as mechanical and thermal pretreatments, or are economically non-profitable such as enzymatic treatments [15].

III. LITERATURE REVIEW

The literature related to various pre treatment methods is briefly summarized below:

C. Sambusiti et. al. [1] made experimental investigation related to comparison of different pre-treatments to increase methane production from two agricultural substrates.

Thermal, alkaline and thermo-alkaline pre-treatments were performed in batch mode to enhance the methane production from ensiled sorghum forage and wheat straw. Alkaline pretreatment was conducted at 40oC for 24 hours with the addition of 1% and 10% NaOH/gmTS. Thermal and thermo-alkaline pretreatments were performed at 100oC and 160oC for 30 minutes, with and without the addition of NaOH solutions.

These pre-treatments resulted in solubilization of the organic matter, with a maximum concentration (around 30–40% for both substrates) obtained at 40oC and 100oC with 10% NaOH. The pretreatments were found to be sustainable for both substrates, especially for wheat straw, due to a higher methane yield increase than that of sorghum.

Huan Li et. al. [2] made experimental analysis on alkaline post-treatment for improved sludge anaerobic digestion.

In this experimentation, 5% of sludge was extracted from a semi-continuous digester with a sludge retention time of 20 days, between the eight and the twelth hour of a 24-hours digestion cycle. The sludge was then disintegrated with 0.1 mol/L NaOH and returned to the digester after neutralization. The post treatment resulted in a 33% enhancement of biogas production in comparison with the control. The change in recycled sludge upto 10% or 15% led to reduction in biogas yield. Alkaline post-treatment had a minimal impact on the dewaterability of digested sludge.

A. Carvajal, et. al. [3] performed experimentation on autohydrolysis pretreatment of secondary sludge for anaerobic digestion.

The secondary sludge was given autohydrolysis pretreatment to a temperature of 55oC for 12–24 hours with a limited amount of oxygen under batch operation. High solubilization of organic matter, increased solubility of the sludge and improvement in biogas production were observed due to autohydrolysis pretreatment. Auto hydrolysis pretreatment for 12 hours, with a high solid concentration and micro aerobic conditions, the solubilization of organic matter was increased by 40%, the methane productivity was improved by 23%.

Xusheng Meng, et. al. [4], investigated experimentally addition of iron oxide powder to enhance the anaerobic conversion of propionate to acetate.

It is thermodynamically difficult to decompose propionate into acetate. To enhance the decomposition of propionate, addition of FeO powder (10 gm) was done into an acidogenic reactor (A1) with propionate as the sole carbon source. The results showed that the propionate conversion rate (67–89%) in (A1) were higher than that in a reference reactor (43–77%) without dosing of FeO (A2).

S. Tedesco, et. al. [5], have experimented on mechanical pretreatment effects on macroalgae derived biogas production in co-digestion with sludge.

Mechanical pretreatment has been applied in batch mode focusing on biogas yields from five different species of Irish seaweeds in co-digestion with sludge. A second experiment on Laminaria Digitata species has been carried out using a Response Surface Methodology (RSM) with treatment times (0-10 min), mesophilic range of temperatures (35-39oC) and sludge amounts (100-300 ml). Biogas yields of treated macro algae have been found to be up to 20% higher when compared to untreated ones.

Zehra Sapci [6], investigated experimentally the effect of microwave pretreatment on biogas production from agricultural straws.

Microwave-pretreated agricultural residual straws are used as feedstock in a laboratory batch study. Barley, spring wheat, winter wheat and oat straw were used in experimentation.

The microwave pretreatment of the different straws was ineffective to improve their anaerobic digestion. An increase in the treatment temperature led to lower biogas production levels. An inverse relationship between the thermal conversion yield and cumulative biogas production was observed.

Yuanyuan Yana et. al. [7] experimentally investigated and obtained enhancement of biochemical methane potential from excess sludge by mild thermal pretreatment.

Mild thermal pretreatment (50-120oC) and its effect on the solubilization and methane potential of excess sludge with a low concentration of organic matters were investigated.

It was observed that potential of methane production from excess sludge is enhanced by mild thermal pretreatment, and under the conditions of pretreatment temperature 100oC and digestion time 20 days.

Huan Li et. al.[8] have made experimental study related to optimization of alkaline pretreatment of sludge before anaerobic digestion.

Sodium hydroxide (NaOH) was used to disintegrate a mixture composed mainly of primary sludge with biofilm sludge before anaerobic digestion in batch experiments. NaOH pretreatment was found useful to dissolve some organic substances, and the optimum dose was determined to be 0.1 mol/L. Alkali-treated sludge was then fed to the digesters. The higher pH caused delay in the start of digestion and reduced the biogas production during the initial stage, although the system recovered after a lag phase when the dose was lower than 0.04 mol/L. Acid conditioning was necessary, but the increased salinity also impacted on the digestion efficiency.

Anna Karlsson and Jorgen Ejlertsson [9], performed experimental investigation by addition of HCl as a means to improve biogas production from protein-rich food industry waste. Four laboratory scale reactors having four liter volume, with an organic load of 3.5 g volatile solids (VS) per liter reactor volume per day, and a hydraulic retention time 24 days were run under mesophilic conditions.

It is observed that lowering the pH by 0.2–0.4 units by adding HCl to the reactors increased the methane yield with about 50%.

Karina Michalska, et. al.[10], have experimentally verified influence of pretreatment with Fenton's reagent on biogas production and methane yield from lignocellulosic biomass.

Biomass from Miscanthus giganteus, Sida hermaphrodita and Sorghum Moensch was chemically treated with Fenton's reagent for 2 hours. The conditions were maintained as pH = 3, mass ratio of [Fe2+]:[H2O2] equals 1:25 for Miscanthus and Sorghum and 1:15 for Sida). The highest biogas production (25.2 dm3/kg TS fed) with a 75% methane content was obtained with Sorghum Moensch. The results underline the necessity of use of chemical pretreatment such as oxidation with Fenton's reagent.

S. Menardo et. al.[11], have analyzed experimentally the effect of particle size and thermal pre-treatment on the methane yield of four agricultural by-products.

Various mechanical and thermal treatments were applied to four agricultural byproducts (wheat, barley, rice straw and maize stalks) prior to anaerobic digestion for different particle size reduction to 5.0, 2.0, 0.5, and 0.2 cm with heat application to 90oC and 120oC.

It is found that mechanical pre-treatment increased methane yields more than 80%; thermal pre-treatment improved yields more than 60% for wheat and barley straw. Pretreatment of wheat straw improves methane yields most, for thermal as well as mechanical pretreatment.

C. Sambusiti et. al.[12], have analyzed experimentally influence of alkaline pre-treatment conditions on structural features and methane production from ensiled sorghum forage.

Different alkaline dosages (4% and 10% gm NaOH/gm TS), at temperatures (40oC and 55oC), and contact times (12 hours and 24 hours) are applied in order to analyze the influence of the pretreatment conditions on the structural features and methane production from ensiled sorghum forage. Improvement in methane yield, as compared to untreated sample (from 8% to 19%), was noted at all pretreatment conditions tested. Also by changing NaOH dosage, temperature and contact time, methane yield did not change drastically.

Anna Teghammar et. al.[15], experimentally obtained enhanced biogas production from rice straw, triticale straw and softwood spruce by NMMO pretreatment.

Softwood spruce (chips and milled), rice straw and triticale (a hybrid of rye and wheat) straw, were pretreated with N-methylmorpholine-N-oxide (NMMO or NMO) prior to anaerobic digestion to produce biogas. The pretreatments were applied at an elevated temperature of 130oC for duration of 1-15 hours, and the digestions period of six weeks.

Pretreatments influenced to improve the methane yields by 400-1200%. The maximum methane yields of the pretreated chips and milled spruce rice straw and triticale straw were 125, 245, 157 and 203 ml CH4/gm of raw material.

Maibritt Hjorth et. al.[16], experimented with extrusion as a mechanical pretreatment to increase biogas production.

Mechanical pretreatment in an extruder has been applied to increase the methane yield in a biogas production and large potential for biogas yield improvement has been observed. An extruder based pretreatment was applied on five agricultural biomass types, represented by 13 samples.

Weizhang Zhong et. al.[17], investigated experimentally the effect of biological pretreatments in enhancing corn straw biogas production.

Complex microbial agents were used for biological pretreatment of corn straw at ambient temperature (about 20oC) to check feasibility of improvement in biodegradability and anaerobic biogas production. A complex microbial agent dose of 0.01% (w/w) and pretreatment time of 15 days were found to be appropriate for biological pretreatment. Results showed that 33.07% more total biogas yield, 75.57% more methane yield, and 34.6% shorter technical digestion time can be achieved by biological pretreatment, as compared with the untreated sample.

Lise Appels et. al. [18], have investigated experimentally the method of alternative pre-treatment for the anaerobic digestion of waste activated sludge by using peracetic acid oxidation.

Solubilisation of organic material can be improved effectively by the use of peracetic acid for disintegrating sludge. Increase in biogas production can be achieved upto 21%. Further increase in dosages of peracetic acid causes a decrease in biogas production, due to the inhibition of the anaerobic micro-organisms by the high volatile fatty acids concentrations.

IV. CONCLUSIONS

From literature cited above, it can be concluded that different pretreatment methods can be applied for improving biogas output from various substrates. A particular pretreatment method can be selected depending upon the type of substrate material used and operating conditions in the reactor. The cost of a pretreatment method should also be taken into account prior to selection of a particular pretreatment method. The amount of improvement in biogas yield should be high enough to justify the cost of pretreatment method employed.

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