METHODS FOR ENHANCING THE METHANE PRODUCTION FROM WASTEWATER - A REVIEW

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ABSTRACT

Developing cost-effective technologies to solve water pollution problems are critical to the sustainable development of human society. Wastewater treatment systems are now experiencing a paradigm shift. Whereas they once merely aimed to remove pollutants, they now also attempt to recover resources while minimising energy consumption. Anaerobic digestion (AD) process is one of the oldest technologies. AD is considered to be an efficient, sustainable, and technically feasible way to treat wastes as it offers the benefits of mass reduction, pathogen removal and generation of methane. The recent demand in renewable sources of energy has boosted application of AD. Wastewaters of various complexity can be treated by AD. The aim of this review is to summarize the recent technological advances in the area of anaerobic digestion for the generation of energy from the wastewater.

Keywords: Anaerobic digestion, Biochar, Electrolysis, Wastewater treatment.

I. INTRODUCTION

Water is indispensable and one of the most precious natural resources of our planet. 97% of the water on the Earth is salt water and only three percent is fresh water. Out of this three percent two thirds is frozen in glaciers and polar ice caps. The remaining unfrozen fresh water is found mainly as groundwater, with only a small fraction present above ground or in the air. Ground water is an important natural source of water supply all over the world. Its use in irrigation, industries and domestic purposes continues to increase where perennial surface water source is absent. Water intended for human consumption should be safe, wholesome and should be free from pathogenic agent and harmful chemicals, pleasant to taste and useable for domestic purposes. The modern civilizations, over exploitations, rapid industrialization and increased population have lead to fast degradation of our environment and the scarcity of water. Among these water pollution is one major factor which will lead to the scarcity of water. Industrial activity affects the environment directly or indirectly. Environmental emission from any industry has impact on air, water and land. It is very much necessary to increase awareness of the fact that clean environment is necessary for smooth living and better health of human beings. Also inorder to meet the rising demand, it is imperative to recognize the fresh water resources and to find out remedial methods for improvement of water quality [13].

Water pollution is the contamination of water bodies, it affects the entire biosphere – plants, animals and organisms living in these water. In almost all cases the effect is damaging not only to the individual species and population, but also to the natural biological communities.

The social, environmental and economic impacts of various industries have led to inevitable conflicts between industrial progress and environmental sustainability. Waste effluents have detrimental impacts on biodiversity, primarily due to their mobile nature. When they are discharged into natural water bodies without substantial remediation, there can be serious, adverse impacts.

Wastewater treatment systems are now experiencing a paradigm shift. Whereas they once merely aimed to remove pollutants, they now also attempt to recover resources while minimising energy consumption. These resource recovery technologies are known as water resource recovery facilities (WRRFs) [7]. Environmental concerns emphasise the recovery or reuse of wastes generated from industry. Waste recycling is not only important environmentally, but also economically, as it affects the running costs of treatment plants. Additionally, the reuse of wastes furnishes a viable solution to the raw material availability that could be harnessed for the generation of energy and fuels. Inorder to reduce the effect caused by water pollution, the maximum energy recovery from the polluted water is essential. That is for the sustainable development of global prosperity, energy recovery and environment protection are the two crucial issues that are to be considered. Energy is a factor that significantly influence the development of civilization. In 2014, among the various energy sources fossil fuels represented 86% of all energy consumed (32 % crude oil, 30 % coal, 24 % natural gas), remaining energy requirement is provided by 7% by hydro electricity, 4% by nuclear energy and 3% by renewable energy. The worldwide energy need has been increasing exponentially and the reserves of fossil fuels have been decreasing. World energy demand is projected to be 37% higher by the year 2035. Analysing the data concerning fossil fuels, it seems that their reserves are not sufficient to meet the energy demand by the end of 21st century.

One way to utilize waste is biogas fermentation in which biomass is transformed into hydrogen and methane. Methane or hydrogen produced in such way could be used as a heating or power source [4]. Biogas represents one of the most highly appreciated opportunities to utilize certain categories of biomass to fulfill partially the world's energy needs. Biogas commonly refers to a mixture of gases produced by the biological breakdown of organic matter in the absence of oxygen. Biodegradable wastewaters contribute as much as 6% of all anthropogenic methane emissions. High-rate anaerobic digesters have the potential to treat such wastewaters efficiently as well as enable capture of methane for use as a relatively clean energy source [17]. The energy output/input can reach up to 28.8 MJ/MJ under favourable conditions, contributing to a very efficient use of the valuable biomass. The resultant energy release allows biogas to be used as a biofuel to replace conventional fossil energy sources (coal, oil, natural gas) in power and heat production, and also as a versatile renewable energy source to fuel vehicles with lower sale price compared to diesel and petrol [5].

II. WASTE TO ENERGY

Waste-to-energy conversion is a process of generating energy from waste, ultimately reducing waste disposal and providing an alternative form of energy. This technique can be used effectively for the treatment of wastewaters which in turn reduces the sludge that is generated by the conventional method. Anaerobic digestion (AD) process is one of the oldest technologies. AD is considered to be an efficient, sustainable, and technically feasible way to treat wastes as it offers the benefits of mass reduction, pathogen removal and generation of methane. AD is a naturally occurring process of decomposition and decay by which organic matter is broken down into simpler chemical components under anaerobic conditions. AD is a multi-step process in which complex organic compounds are converted to the most oxidized and reduced forms of monoatomic carbon (carbon-dioxide and methane respectively). The initial processes of hydrolysis and fermentation are mediated by bacteria, while subsequent processes of anaerobic oxidation of organic acids and alcohols to acetate (acetogenesis), and methanogenesis, are mediated by bacteria and archaea respectively. Hence AD is the most efficient method for the generation of energy from wastewaters. Anaerobic treatment converts dissolved COD in the waste to methane, by the action of methanogenic bacteria. Anaerobic digestion is the default process for biological conversion of residue organics to renewable energy and biofuel in the form of methane. However, its scope of application is expanding, due to availability of new technologies, and the emerging drivers of energy and nutrient conservation and recovery.

III. IMPROVEMENTS OVER CONVENTIONAL AD PROCESSES

The biogas produced from AD usually contains small amount of hydrogen sulphide and ammonia as well as trace amount of other gases. Methane production from AD is identified as a suitable process to produce bioenergy but the poor biomass quality is one of the main reasons for low average useful energy production from anaerobic digestion.

The recent demand in renewable sources of energy has boosted application of AD. Wastewaters of various complexity can be treated by AD. However, its application for energy recovery is limited by the presence of hydrogen sulfide in the biogas, the slow hydrolysis of complex organic matter under anaerobic conditions, the high sensitivity of anaerobic microorganisms to variations in wastewater composition and the requirement of influent with a high concentration of organic matter [16].

There are several ways to improve biogas production in AD processes. Some of the methods that are used to increase the yield of the AD processes are the use of an active biomass, addition of nutrients essential for the growth of microorganisms, addition of trace elements essential for the growth of microorganisms, modifications of the reactor from the conventional, by the addition of biochars and also by the electrolysis of waste water. A well-working, active biomass is a prerequisite for efficient biogas production processes. The microorganisms need nutrients, i.e. carbon, nitrogen, phosphorus, calcium, potassium, magnesium as well as trace elements such as iron (Fe), Copper (Cu) , Zinc (Zn) , Manganese (Mn), Nickel (Ni), Cobalt (Co), Molybedieum (Mo), Selenium (Se). Thus, the addition of trace metals increase process efficiency by enhancing substrate digestion and biogas production combined with low concentrations of intermediate fermentation products i.e. volatile fatty acids. These improvements are due to the fundamental necessity of metals as micronutrients for almost any form of life and also due to the crucial role that the metal plays for the intracellular synthesis and activity of essential metabolic enzymes and cofactors governing growth.

Differently designed and configured bioreactors significantly affect the process of methane production, particularly in terms of retaining stability and efficiency. Some of the common bioreactors used are dry anaerobic digestion, field scale plug flow reactors, anaerobic sludge blanket reactors (UASB), continuously

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stirred tank reactor (CSTR), induced bed reactors (IBR) and anaerobic membrane bioreactors (AnMBR). Another bioreactor arrangement included a degassing membrane unit coupled with a UASB reactor which is found to improve the methane production rate to about 94% with a liquid recirculation rate equal to 0.63 L/h [8]. Biochar is a carbon rich residue formed from the thermal decomposition or pyrolysis of biomass. Biochar can be used to enhance biogas production in AD due to its ability to promote biofilm formation, mitigate ammonia, reduce lag phase and acid inhibition [15]. Electrolysis enhanced AD can also serve as an innovative method for increasing methane production. Electrolysis enhanced AD results in a continuous supply of oxygen and hydrogen. The oxygen will create micro-aerobic conditions, which facilitate hydrolysis of synthetic wastewater and will reduce the release of hydrogen sulfide to the biogas. A portion of the hydrogen produced electrolytically will escape to the biogas improving its combustion properties, while another part will be converted to methane by hydrogenotrophic methanogens, increasing the net methane production [16]

Fagbohungbe et al. (2016) studied the impact of different types of biochars and biochars ratios on the anaerobic digestion of citrus peel wastes. The different biochars that were used in the study are Wood biochar (WB), coconut shell biochar (CSB) and rice husk biochar (RHB). They showed that the WB recorded the shortest lag phase while the CSB achieved the highest methane production when comparing the effect of different biochar on anaerobic digestion of citrus peel.

Sunyoto et al. (2016) studied the effect of biochar addition on methane production in two-phase anaerobic digestion of aqueous carbohydrates food waste in batch mode. They have concluded that the Biochar addition shortened the lag phase for the methane by 41–45%, increased the maximum methane production rate by 23.0–41.6% and CH_4 production potential by 1.9–9.6% of CH_4. Thus it is speculated that biochar provided temporary substrates to support microbial metabolism and growth promoted the methanogenic biofilm formation in the methane production.

Shen et al. (2016) conducted a study on Towards a sustainable paradigm of waste-to-energy process: Enhanced anaerobic digestion of sludge with woody biochar. They concluded that the two woody biochars tested, pine biochar (PBC) and white oak biochar (WOBC) resulted in average methane content of up to 92.3% and 89.8% in the biogas produced during AD of sludge at mesophilic temperature and up to 79.0% and 78.5% in the biogas produced at thermophilic temperature respectively.

Narra et al. (2016) conducted an investigation on the Enhancement of biogas production from rice straw (RS) by selective micronutrients under solid state anaerobic digestion. Biomethanation of RS was studied in a batch mode at high total solid content (TSC) of 25% in outdoor pilot scale digesters. The performance was monitored for over six months by supplementing Nickel and Cobalt at 15 and 10 mg kg^{-1} RS to each of mesophilic and thermophilic digesters for 35 and 21 days retention time (RT), respectively. The average biogas production from mesophilic and thermophilic digesters were found to be 310 and 396 L kg^{-1} TS, respectively. They have shown around 37 and 46% higher biogas production by supplementing the micronutrients in mesophilic and thermophilic digesters, respectively. They have also observed that the methane content in biogas was 57–59%.

Wang et al. (2016) investigated the Enhancement of anaerobic degradation of Fischere Tropsch (F-T) wastewater by integrated UASB system with Fe-C micro electrolysis assisted. The study was done using coupled UASB system in three reactors with IC-ME for F-T wastewater treatment. The COD removal efficiency and methane production in the reactor 1 with IC-ME assisted both achieved 80.6 ± 1.7% and 1.38 ± 0.11 L/Ld under the optimum HRT of 5 days.

Bozym et al. (2015) analysed the effect of metal concentrations in food wastes for biogas production. The waste mainly consisted of by Pb, Cd, Cu, Zn, Cr, Ni, Na, K, Mg and Ca. They have concluded that the above mentioned metals will enhance the formation of biogas. It is also found that high levels of heavy metals can reduce the effectiveness of or completely inhibit biogas production. They have also mentioned that the negative influence exerted by heavy metals on anaerobic digestion is determined not only by their concentrations in the substrate, but also by their chemical form, oxidation state, pH of the feedstock and interactions with other compounds, including antagonistic metals.

Ahmed et al. (2015) discussed about the Production of biogas and performance evaluation of existing treatment processes in palm oil mill effluent (POME). They concluded that POME are markably contaminating effluent due to its high amount of COD, BOD and colour concentrations which can affect the environment especially water resources. However, it was recognized as a prospective source of renewable biogas such as biomethane and biohydrogen.

Akinbomi et al. (2015) conducted a study on the Enhancement of Fermentative Hydrogen and Methane Production from an Inhibitory Fruit-Flavored Medium with Membrane-Encapsulated Cells. The study maily focused on the possibility of improving fermentative hydrogen and methane production from an inhibitory fruit-flavored medium using polyvinylidene fluoride (PVDF) membrane-encapsulated cells.

Ariunbaatar et al. (2014) studied the different pretreatment methods to enhance anaerobic digestion of organic solid waste. The growing global concerns on the increasing amount of waste, energy demand, and global warming have stimulated research on the acceleration and enhancement of the AD process. Pretreatment methods can be categorized as mechanical, thermal, chemical, biological or a combination of them. Among the widely reported pretreatment

methods tested at lab scale, only few mechanical, thermal and thermochemical methods were successfully applied at full scale. Based on a simple sustainability assessment, they concluded that only thermal pretreatment (at low temperatures) and two-stage AD systems offer more advantages as compared to the other pretreatment methods. As they give higher biogas yield, decisive effect on pathogen removal, reduction of digestate amount, reduction of the retention time, better energy balance and better economical feasibility.

Zhang et al. (2013) studied the Effects of ferric iron on the anaerobic treatment and microbial biodiversity in a coupled microbial electrolysis cell (MEC) - Anaerobic reactor. They concluded that adding Fe(III) into a MEC anaerobic reactor enhanced the degradation of organic matters. The addition of $Fe(OH)_3$ enhanced both anaerobic digestion and anodic oxidation, resulting in the effective mineralization of volatile fatty acids (VFAs).

Opwis and Gutmann (2012) studied the generation of biogas from the textile wastewaters. They showed the microbial fermentation of textile desizing liquors into biogas by using a double-stage biogas reactor with biomass recirculation. The biogas with high methane content up to 60 volume (%) was produced in a simple biogas reactor with biomass recirculation and pH control without further treatment of the sugar-containing medium. Thus they have shown that the textile industry waste waters can be used for the generation of energy combining ecological and economic benefit. Moreover, this new process reduces the COD of the waste water by more than 85 %.

Ukpai and Nnabuchi (2012) conducted a comparative study of biogas production from cow dung, cow pea and cassava peeling using 45 litres biogas digester. The result obtained from the gas production showed that cowpea produced the highest methane content of 76.2%, followed by cow dung with 67.9% content and cassava peeling has the least methane content of 51.4%. The cow dung had the highest cumulative biogas yield of 124.3 L/total mass of slurry (TMS) while cow pea had 87.5 L/TMS and cassava peeling with lowest cumulative biogas yield of 87.1 L/TMS within the retention period. The study also revealed further that cow dung as animal waste has great potentials for generation of biogas and its use should be encourage due to its early retention time and high volume of biogas yields. Also in this study, it has been found that temperature variation, pH and Concentration of Total solid etc are some of the factors that affects the volume yield of biogas production.

Tartakovsky et al. (2011) studied the effect of electrolysis-enhanced anaerobic digestion of wastewater by using titanium mesh anode with Ir-MMO coating and a stainless steel mesh cathode in two upflow anaerobic sludge bed (UASB) reactor. They have concluded that by conducting water electrolysis in the sludge bed of UASB reactors at a low current density the process performance improved in several ways. The micro-aerobic conditions increased the rate of hydrolysis of organic matter thus improving COD removal efficiency and methane production. Electrolytic H_2 improved the combustion properties of the biogas and increased net methane production through hydrogenotrophic methanogenesis. The microbial activity consumed almost all of the oxygen while the H_2S concentration in biogas was significantly reduced. Also the methane production was increased by 10-25% and reactor stability was improved in comparison to a conventional anaerobic reactor.

IV. CONCLUSION

In conclusion, the efficiency of anaerobic digestion for the generation of methane can be improved by addition of naturally available biochars and also by electrolysis. The biochars formed from the coconut shells are found to be very effective in improving the methane concentration. They also help in reducing the pollution of the natural waters.

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