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Effect of nano addition on biogas production from different substrates: A review

Ghada Heikal[a], Ahmed Abdo[b] and Mohamed A. A. shakrum[c*]

[a]*Associate Prof. in Environ.Eng. Department,Faculty of Engineering, Zagazig University.*
[b]*Lecturer in Environ. Eng. Department, Faculty of Engineering, Zagazig University*
[c]*B.Sc. Chemical Engineering -Faculty of Engineering-SirteUniversity, Department of chemical engineering*

A R T I C L E I N F O

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A B S T R A C T

Anaerobic digestion is a biochemical process used globally to convert the organic matter present in wastes into a process enhancing biogas production. Biogas production via anaerobic digestion (AD) of wastes is a very attractive, yet a challenging task. The slow rate of biodegradation and the presence of impurities in biogas expose the whole process to several risks. However, the addition of nanoparticles (NPs) can influence the performance and stability of the AD process. AD is a complex biochemical process which converts complex organic wastes into a gas mixture containing methane (CH_4), carbon dioxide (CO_2), water vapor, hydrogen sulfide (H_2S), hydrogen, and ammonia. The sluggish rate of biodegradation of complex organic substrates, i.e., ligocellulosic substrates, limits the performance and efficiency of the AD process. Furthermore, because of hazardous components that may impair the efficiency of the AD process, such as organic matter and ammonia in wastewater and various organic, substrates may need pre-treatment such as thermal and acidic/alkaline. Nanotechnology a growing impact on a wide range of microbiological, pharmaceutical, and pure technological applications. The current application in production benefits from producing bioenergy from biomass is still highly limited. This work examines the effects of NPs additions on the AD. In addition, this research covers the benefits and the drawbacks of nanoparticles in producing of biogas.

1. Introduction

Greenhouse gases (GHG), such as carbon dioxide CO2 and methane (CH4), which emit through human activities, trap the infrared radiation coming from the sun and raise, consequely the temperature of the earth. During the biological treatment processes,

Wastewater treatment plants (WWTPs) produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) within addition to CO_2 that emits due tothe production of the energy required for the plant operation [1]. Previous studies of wastewater treatment facilities have found that biogas production can generate 60 to 100% of energy required to operate these facilities [2]. Biogas is formed as a result of methanogenesis during anaerobic digestion (AD). This gas is composed mostly of $CH_4$and CO_2, but it can also contain trace amounts of hydrogen sulfide, nitrogen, oxygen, and hydrogen. Table 1 shows the typical composition of biogas generated through anaerobic digestion [3]. Biogas is a renewable source of energy produced by the AD of animal

* Corresponding author. Tel.: 0 114 476 8097
E-mail address: . Shkroom1973@gmail.com

manure, agricultural residues organic wastes of food sewage sludge and different energy crops [table 2].AD of sewage sludge offers numerous significant advantages, including green energy recovery, low energy requirement and reduction in sludge volumes. However, the efficiency and operational stability of the AD of sludge is highly limited due to the slow rate of hydrolysis reaction. This leads to a low methane production efficiency and a remarkable lack in energy recovery. Several factors including pH, sCOD, ammonia-nitrogen concentrations and microbial community, affect the performance and stability of the AD process [4].

Table (1): The biogas composition [4].

Compound	Chemical formula	**Yield (%)**
Methane	CH_4	50–75
Carbon dioxide	CO_2	25–45
Water vapor	H_2O	2–7
Nitrogen	N_2	< 2
Oxygen	O_2	< 2
Hydrogen sulfide	H_2S	< 1
Hydrogen	H_2	< 1
Ammonia	NH_3	< 1

Nanomaterials can positively affect the levels of these factors in the AD systems. The effect of nanomaterials on the AD process and consequently on the biogas yield is an active area of research. Nanomaterials have an impact on the AD process due to their unique properties,including the adsorption reduction of heavy metals,the degradation of organic matters , the During the biological treatment processes,reduction of hydrogen supplied and the mprovement of AD efficiency as an electron donor [5].

Table (2): AD feedstock and Biogas yield [4] .

Substrates	**Biogas yield (m^3/tF)**	Methane (%)
Liquid pig manure	28	**65**
Liquid cattle manure	25	**60**
Distillers grains with soluble	40	**61**
Pig manure	60	**60**
Cattle manure	45	**60**
Chicken manure	80	**60**
Organic waste	100	**61**
Beet	88	**53**
Sweet sorghum	108	**54**
Grass silage	172	**54**
Corn silage	202	**52**
Forage beet	**111**	**51**

In addition, nanomaterials can also affect microbes within breaking the competition between microorganisms, promoting microbial growth and destroying cell membranes. The unique properties of nanoparticles make it an excellent additive in sludge AD; however, excessive nanoparticles can cause toxicity to microorganisms. Nanoscale zero-valent iron (NZVI), is increasingly used for environmental remediation and has a potential positive impact on AD. In the AD process of sludge (Fig. 1), hydrolysis is the first step in which large polymers react with water to form smaller organic compounds. The next step is the acidification where the products of the hydrolysis step are converted to organic acids. The organic matter released by the decaying microorganisms is the main source of anaerobic bacteria. But the decaying cell wall (membrane) is resistant enough to break by the processes of hydrolysis and acidification using organic matter [6]. The NZVI can adsorb cells, due to electrostatic interactions, and disrupt cell membranes by inducing a reductive stress, which greatly enhances the release and utilization process of intracellular organic matters. Fang et al. [7] found that with the NZVI, in case of heavy concent ration in the AD system, NZVI gradually adsorbed on the surface of cell membrane and enters the cell interior, which causes the microbial cells to break down and release a large amount of organic matter and hydrolase. Accordingly, the hydrolysis and acidification processes of the sludge are strengthened and the methane production is enhanced. Accordingly, the hydrolysis and acidification processes of the sludge are strengthened and the methane production is enhanced.

Furthermore, zero-valent iron can increase the activities of several key enzymes in the hydrolysis and acidification process. NZVI not only strengthens the hydrolysis and acidification process but also releases an electron donor to reduce CO_2 to methane under the action of hydrogenotrophic methanogens [8].

Fe_3O_4 nanoparticles (Fe_3O_4 NPs) is a mixed valence magnetic mineral containing both Fe^{2+} and Fe^{3+} in a proportion of 1:2. The positive effect of Fe^{2+} on methanogenesis is recognized since Fe_3O_4 NPs increase the methanogenic activity associated with the accelerated organic degradation. [9,10]. In the AD process, microbial nanowires directly transfer electrons, generated by intermediates, from syntrophic bacteria to methanogenic archaea. Archaea uses the electrons obtained to reduce carbon dioxide (CO_2) and ultimately produces methane [11].

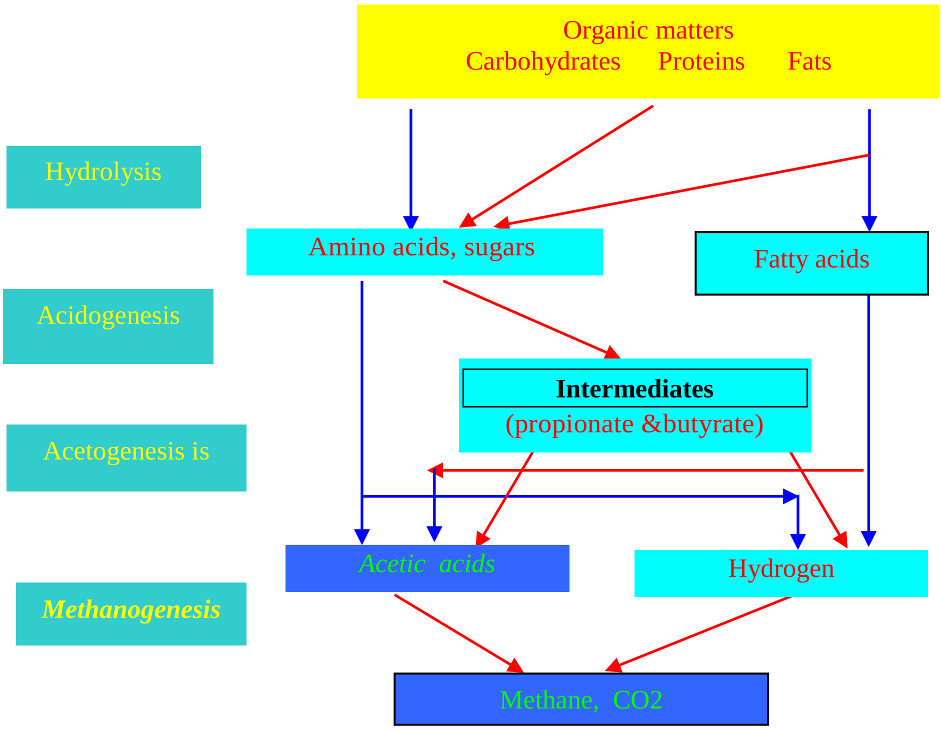

fig. 1: The anaerobic digestion stages [11]

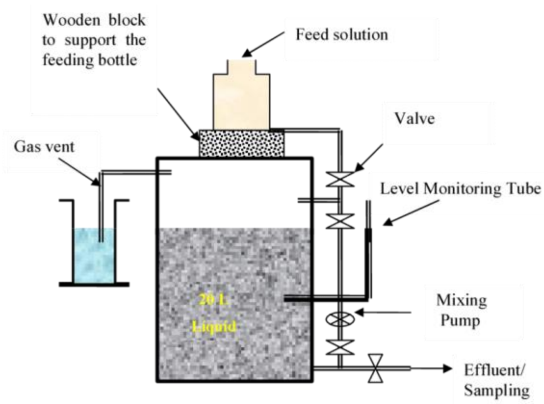

fig. 2 : Schematic diagram of anaerobic digester[11]

2. Impact of Nano-additives on biogas production

The effect of nano-additives on the AD process and consequently on the biogas yield is an active area of research. Physicochemical characteristics of nanomaterials including surface structure, size, specific surface area, solubility and catalytic nature, make them advantageous in many applications. Nanomaterials possess a capacity to penetrate through cell membranes, making them useful in several biological applications [12]. The addition of nanoparticles increase also the methane formation rate and reduces the lag phase [13].

2.1. Carbon-based additives

Carbon-based additives have been widely employed to enhance methanogens. These additives encompass granular activated carbon (GAC), powder activated carbon (PAC), biochar, carbon cloth, single walled carbon nanotube, multi walled carbon nanotube, graphite and graphene. Zhao et al. [14] studied the influence of GAC on the production of methane within the anaerobic digestion of synthetic wastewater in this study,

Implementing GAC at a concentration of 40 g/l increased methane generation by 59% compared to that of a control sample. A 17.4% increase in methane generation was observed when the anaerobic digestion process of waste activated sludge was enhanced by GAC with concentrations ranging between 0.5 and 5 g/l. The presence of GAC accelerated the transfer of electrons between fermenting bacteria and the methanogen. [15].

The effects of biochar on methane production have also been studied. For instance, a 21% increase in methane formation has been reported at a concentration of 10 g/l. Porous biochar wasreported tosupport biofilm growth and coarse biochar was observed to improve methane production compared to that of fine biochar. A 30–45% enhancement in methane generation was noticed via the use of waste activated sludge treated with biochar. The electrical conductivity of biochar is notably lower than that of GAC, but the increase in methane generation is almost as effective as for GAC [16].

Implementing carbon cloth in the anaerobic digestion process was seen to increase methane generation by 1.3 times compared to that of a control sample [17]. Grapheme, a layered nanostructure with highly electrical conductivity, intensively mechanical strength and greatly thermal conductivity has been demonstrated to improve methane generation. The introduction of grapheme to an aerobic digestion having waste activated sludge as a feedstock enhanced methane production by 25% relative to the activated carbon [18]. The impact of grapheme concentration on the anaerobic digestion has been examined for two concentrations (30 mg/l and 120 mg/l) and it has been observed that methane generation increased by 17% and 51% respectively [19]. On account of their high strength, little measurements, and productive physicochemical provisions, utilizations of carbon nanotubes have notably received much interest lately. Li et al. [20] reported that slop treated with single divider carbon nanotubes (SWCNTs) at a convergence of 1 g/l with sucrose as the substrate could spport methane production rate by two overlays.

On the other hand, Yan et al. [21] showed that Slop treated with GAC and SWCNTs (1000 mg/l), utilizing glucose as a substrate, created identical measures of methane [21]. Zhang and Lu [22] observed an enhancement in methanogenic activity of lake sediments treated with multi wall carbon nanotubes (MWNCTs) at a concentration of 5 g/l in addition to an enhancement in methane generation of 50%. A MWCNT concentration of 1500 mg/l as an additive to the seed sludge enhanced the cumulative methane generation by 43% in comparison with that of a control sample after 96 h of AD. Ajay et al. [23] checked out the impacts of fullerene (C60) NP on the AD of wastewater muck for a couple of months. C60 was presented in two structures: one disintegrated in MeOH/EtOH at 321 mg/g biomass, and one more in watery arrangement at 8.6 mg/kg biomass. Others were kept over dried slime containing toluene and o-Xylene at convergences of 30and 50g/kg biomass individually. There was no change in the biogas yield for the concentrated examples as a whole, as indicated by the discoveries. Luo et al. [16]. examined the impacts of miniature/nano fly debris (MNFA) and miniature/nano base debris (MNBA), got from a civil strong waste incinerator, on the AD of MSW at a mesophilic temperature (35 1 C) for 90 days. MNFA and FA were used at centralizations of 0,12, 3, 6, 18, and 30kg/kg VS individually, and MNBA and BA were utilized at convergences of 0.6, 12, 36, 60, and 120kg/kg VS separately. The outcomes showed a significant expansion in the biogas production when contrasted with the control test much of the time of FA, MNFA, BA, and MNBA, with the greatest increment of 36g/g VS MNBA. The creators credited the ascent in the biogas production found in the wake of utilizing FA and BA to the mixtures present in them (like $Al2O_3$, $CaCO_3$, $Ca(OH)_2$, SiO_2, Ca_3SiO_5, Ca, Mg $(CO_3)2$, Ca_2SiO4, PbO, and ZnS). They credited the ascent in MNFA and MNBA creation to the accumulation idea of nano-substances, which give more homes for anaerobic living beings [24].

2.2. Iron Nanoparticles Additives

Iron oxide nanoparticles have been used in research extensively over the last few years because of their super magnetic characteristics, unique electronic properties, high surface-to-volume ratios and catalytic properties. The low oxidation reduction potential and electron donating nature of iron oxides enhance the methanation process. Kato et al. [25] observed an enhancement in the methane production at a concentration of 20 mM. similarly, Jing et al. [26] observed a 44% increase in the methane production rate from a feedstock treated with 0.01 to 0.1 g/l of magnetite. Liu et al. [27] obtained similar results, showing increase in methane production rate. A 15.4% increase in methane production and 13.9% reduction in the lag phase were observed from sludge treated with 10 g/l of magnetite [28].

Numerous studies have been done to detect the influence of iron oxide nanomaterials on anaerobic digestion. In this context, Ambuchi et al [29] observed that adding iron oxide nanoparticles at a concentration of 750 mg/l to seed sludge increased the methane generation by 38% in compared with control sample. They found that the substrate yielded a good response, six hours after the addition of the nanoparticles, in terms of biogas generation.

This suggests that time is a significant factor in the stabilization of nanoparticles. It was also noted that the inclusion of iron nanoparticles induces the growth of bacteria that facilitate the biomethanation process. Magnetite iron oxide nanoparticles (Fe3O4) were seen to improve the bio-stimulating effect of methanogenic bacteria and yield the highest percentage of biogas and methane contents. On average, the biogas and methane yields from the substrate treated with 20 mg/l Fe3O4 nanoparticles improved by 66% and 96% respectively in comparison witha control sample [30].

In general, nanoparticles are available in various sizes. In this regard, 7 nm and 24 nm sized Fe_3O_4 were added to the anaerobic digestion process to determine their impact on biogas generation. The study showed that biogas production stopped on the 21^{st} day in the absence of nanoparticles and the generation of biogas continued until the 40^{th} day in the presence of nanoparticles. This demonstrates the positive impact of adding magnetite nanoparticles. substrate treated with 7 nm Fe_3O_4 nanoparticles increased the biogas formation by 93% over that of the control sample. However, no enhancement of biogas generation was noticed for a feedstock treated with 24 nm nanoparticles [31].

In addition to the size of nanoparticles, concentration of nanoparticles in the substrate also influences the anaerobic digestion. Suanon et al. [32] used 0.75 and 1.5 g of nanoscale magnetite as an additive to the substrate (150 g) separately. The former increased the methane generation by 26% in comparison with the control sample. A high concentration of magnetite (1.5 g) was seen to inhibit methane generation, decreasing it by 11.5% when compared to a control condition. Zhang & Wang [33] obtained similar results, stating that the toxicity effect on AD inhibits methane production. Along the same line, the impact of Fe_3O_4 nanoparticles on methane production at several concentrations (50, 75, 100, 125 mg/l) was studied. The maximum methane yield, which was 53.3% greater than for the control condition, was observed from a substrate treated with 75 mg/l iron oxide nanoparticles. The study showed decrease in methane production as the concentration of iron oxide nanoparticles increased. This may relate to the accelerating hydrolysis and enzymatic uptake activity [34].

A reduction in methane generation with an increase in concentration was reported, and the optimal concentration was found to be 0.5 mg/l among 0.5, 1, 2, 4 mg/l of Fe_3O_4 nanoparticles. An increase in the iron oxide nanoparticle concentrations up to 100 mg/l for the substrate treated with various concentrations (i.e., 20, 50, 100 and 200 mg/l) increased the methane content. A 58.7% enhancement in the cumulative methane production is reported for a concentration of 100 mg/l in comparison with that of the control condition. The methane content declined to 52.3% with the inclusion of 200 mg/l iron oxide nanoparticles. This is attributed to the generation of more CO_2 with the inclusion of nano materials. The study also reported an increase in the methane content only three days after the start-up of the AD process, indicating the time requirement for methanogen microorganism to adapt to the substrate on addition of iron oxide nanoparticles [35]. These results are in good accordance with those reported by Chen et al. [36] and Amen et al. [37] who noticed an improvement in biogas generation due to the enhancement of methanogenic activity on addition of iron oxide nanoparticles. they reported that methane generation improved by 25% over that of control sample.

Treating sludge with nanoscale zero-valent iron (nZVI) nanoparticles improves hydrolysis and methanogenesis activities. A 45.8% increase in methane content is observed from a substrate treated with 0.75 g of additive. This result is in agreement with the study of Feng et al. [8].

the influence of zero-valent iron on the anaerobic digestion process enhanced the methane production up to 43.5%. Iron nanoparticles of a high concentration (1.5 g) decreased the methane production by 29.7% in compassion with that of the control condition (without nanoparticles) due to the effect of toxicity. Iron nanoparticles, being an average size of 20–40 nm, aretreated with substrate at various concentrations such as 3, 9, 15 mg/l. The inclusion of iron nanoparticles in all concentrations improved the start-up phase of biogas generation and decreased the lag one The highest biogas yield is obtained from the reactor with 9 mg/l recording33.3% greater than that of the control sample [38].

Excessive concentration restricts the methanogenic activity as NPs become toxic according to the results of Ganzoury and Allam [39] and Li et al., [40]. they assert that Iron NPs with a concentration of 1 to 10 mg/l should be employed to increase biogas production Under a mesophilic temperature of 35°C, a group type anaerobic framework comprising of a five-liter biodigester was treated with different convergences of NZVI NPs for 100 days with 20 days of pressure driven maintenance time (HRT). The expansion of NPs improved biogas creation, and it was guaranteed that expanding the amount of NZVI nanomaterials could diminish biogas creation full stop however didn't restrict this is on the grounds that biogas yield stayed higher than in the control sample[41].

In the AD measure, the size of an added substance straightforwardly affects the reactor science, and this, in turn, has an influence on the methanogenesis interaction. In contrast with mass NZVI particles, the impact of NZVI NPs on methane production has been examined. The expansion of NZVI NPs to a substrate enhanced biogas creation by 28%, but the expansion of mass iron particles just expanded biogas creation by 5% over the control condition [42]. This embodies the benefits of lessening the material size to a nanoscale. Surfactant use is additionally significant in expanding methanogenic movement by ensuring nanoparticle steadiness The methane content of biogas is a significant measurement for surveying the productivity of the AD measure. The CH4 content in biogas that was created by muck and treated with NZVI NPs and iron powder expanded by 3.1% and 11.6% separately when compared with the control sample or group [43].

Farghali et al. [44] investigated the effect of microscale iron powder and Fe_3O_4 NPs on gas creation from excrement AD. In a mesophilic, a group type anaerobic framework with a 1-liter digester worked for 30 days at 38 °C. The study distinguished an increment in biogas creation from the substrate treated with microscale iron powder when contrasted with Fe_3O_4 NPS. The convergence of iron powder expansion decidedly affects biogas production. When contrasted with a control reactor, biogas generation, from dairy fertilizers, treated with 1 g/l microscale squander iron powder expanded by 52.9 percent. Iron oxide NPs are additionally gainful to biogas creation as an ongoing review has uncovered that iron oxides straightforwardly further develop methane blends through IET. Squander iron powder has a more noteworthy molecule size than Fe_3O_4 and greater particles are more effective in mass exchange to strong and fluid digestate than powdered structures. These points are supported Xu et al. [45] who found that adding 16 mm breadth iron to a substrate can expand CH_4 content by 21% in compassion with 14.50 percent for 0.02 cm iron powder.

Recently, the impact of zeolite-covered nanoscale iron particles on AD has been examined. Zeolite is comprising of tetrahedral AlO4 & SiO4 units. Iron NPs can be caught in the pores of zeolite and fixed on its surface, permitting it to act as a exchanger and increment particle trade limit [46]. The biogas profile of a substrate treated with NZVI covered with zeolite can be separated into 2 phases. Biogas production decreased during the first phase, which lasted until the 8th day, and increased dramatically in the second phase, which lasted from day 8 to the end. The substrate treated with NZVI yielded the most CH_4 (88%) at the and end of the 14th day. On the 14th day, the total biogas yield, from the substrate treated with NZVI covered with zeolite, was 1.450 l, in comparison with0.350 l under control circumstances. As a result, adding NZVI and zeolite to the biogas production process increased it [47].

2.3. *Other Additives*

2.3.1. Nickel (NI)& Cobalt(Co) NPs:

NI and Co metal have been discussed as beneficial trace mineral additives for the methanogenic bacteria growth and biogas system stability. The effect of different concentrations of co and Ni NPs on the production of biogas from cattle dung has been examined [48].

However, there was an adverse consequence on biogas creation at a grouping of 2 mg/l. When contrasted with a control test, the normal methane content of feedstock treated with 1 mg/l cobalt NPs expanded by 41.9 percent. The expansion of 2 mg/l cobalt NPs to the feedstock decreased the methane content by 12.7 percent when contrasted with the control test. However, there was a negative effect on biogas production at a concentration of 2 mg/l. In comparison with the control test, feedstock treated with 1 mg/l co NPs had a 41.9% increase in the CH4 content. When compared to the control test, the addition of 2 mg/l co NPs to the feedstock reduced the CH4 content by 12.7 present [49]. At higher groups of co NPs, a small amount of poisonousness has been accounted for. The formation of biogas and the presence of CH_4 were shown to be related to NI NPs up to 2 mg/l. When compared to the control test, the mean CH4 centralization of the substrate treated with 2 mg/l NI NPs increased by 101%. [50].

The outcomes of NI NPs fixations are harmonious with those of Bozym et al documentation is missing. it is not really settled that the poisonousness edge for NI in the matured waste is 0.01 g/l. Co and NI NPs convergences of 1 mg/l and 2 mg/l are not set in stone to be awesome for getting the substrate increment biogas yield and methane content. Zheng et al. [51] confirmed that the presence of co and NI components in the AD helps the biogas production and CH4 content by assessing measure soundness. Zaidi et al. [52] utilized Co NPs with a distance across of 100 nm in AD. When contrasted with a control test, the researchers tracked a 9 % increment in biogas creation was recorded. A substrate treated with 1.34 g/Kg VS NI NPs (58–80 nm) brought about a 38.4 % increment in the methane creation In contrast with the control test, adding 0.16 g/kg all out solids (TS) NI NPs (100 nm) to t squander initiated muck improved the CH4 emanation by 32% [53].

2.3.2. Addition of Different Metal Oxides

Regardless of the way that these materials can incorporate poly aniline nano-poles, treated silver, alumina, steel, zinc, titanium oxide, cerium oxide, and gold, any examinations on further nanomaterial added substances have been scarcely distributed in the writing. Utilizing hardened steel conductive material at fixations going from 0.2 to 0.8 g/l, Li et al. [54] revealed a 4.5% crease expansion in the methane production. Scientists have shown that conductive polymers can be utilized instead of conductive materials made of iron and carbon. The impact of poly aniline nano-poles at a centralization of 600 mg/l has been considered. In comparison with a control scenario, the researchers discovered a 2-overlay expansion in the CH4 production [55].

The effect of silver, titanium dioxide (TiO_2), cerium dioxide (CeO_2), and gold NPs on biogas production from AD of sewage slime was concentrated on utilizing an anaerobic framework with a one liter biodigester that exposed to a mesophilic of 37 °C for 50 days [56]. CeO_2 totally repressed the methanogenic action, bringing about nil biogas creation fullstop Although silver NPs had a harmfulness of generally 33%, gold and titanium dioxide NPs displayed a minor restraint in biogas creation [56]. The whole hindrance of biogas creation coming from the CeO_2-treated substrate is predictable with the discoveries of Jin et al. [57] who found 11% expansion in the biogas creation (from a sample treated with a low fixation (0.01 g/l) of CeO_2 NPs. CH_4 discharge diminished when the fixation portion moved over 100 mg/l. This could be inferable from cerium oxide's helpless scattering properties in anaerobic conditions, just as the likelihood that the presence of high strong material can restrain theCH_4 production. A substrate was tested by 2 types of TiO_2 (0.1 & 0.5 g/l) and a combination of Fe_2O_3 and TiO_2 something missing here because of metal oxide NPs on biogas creation and hydrogen sulfide content [58]. In comparison with the control sample, the substrate was treated with 0.5 g/l TiO_2 NPs creating 1.17 and 1.21 occasions more biogas and methane. According to the findings, methane generating from the substrate treated with individual metal oxide NPs is higher than that of the consolidated example [58]. These findings are in line with those of Garcia et al .[56] and those of Cervantes et al. [59] who showed 10.0% and 14.9% growths in biogas production when contrasted with control tests individually. Hydrogen sulfide levels were brought by 53 down to 62 percent during the trial [58].

In view of their physicochemical elements, ZnO NPs are utilized in the anaerobic absorption measure. When contrasted with a control test, biogas created from a substrate treated with zinc oxide NPs was decreased by 15% [59]. For 105 days, Wang et al. [60] examined the drawn-out effect of ZnO NPs on the AD of waste-actuated slop (WAS). Three distinct focus - ZnO NPs (1.35 and 150 g/Kg complete suspended strong TSS were added to WAS .Although the option of 1mg/g TSS ZnO NPs showed a real impact on the creation of methane ,the option of 35 TSS at 150mg/g diminished the methane production by 81.7 % and the benchmark group by 24.9% . Unsar and Perendeci [61] focused on the effect of Al_2O_3 NPs on the creation of biogas from squander initiated ooze over the long and present moment. A 48-day long haul biochemical methane possible test and a 72-hour momentary anaerobic restraint test were done by the creators. At groupings of 50, 250, and 500 mg/g, separately, methane creation from squander enacted ooze treated with Al_2O_3 NPs has already expanded by 13.5, 15.8, and 8% in comparison with the control test (according to the drawn-out tes). Al_2O_3 had no impact on methanogenic movement subsequently. There was no considerable expansion in biogas created from the squander actuated muck treated with different centralizations of Al_2O_3 NPs in the momentary testing [62]. Wang et al. [60] explored the impacts of TiO_2, SiO_2, Al_2O_3, and ZnO NPs on the anaerobic processing of WAS at portions of 6, 30, and 150 mg/g TSS. The addition of TiO_2, SiO_2, and other oxides had no effect on production. At all given concentrations, as well as by the addition of Al2O3, TSS ZnO NPs, 6 mg/g However, it drops to 77.2 percent and 18.9%, respectively. when 30 and 150 mg/g TSS ZnO NPs area dded, respectively. The study showed that the Any of the added ingredients had no effect on the solubilization process. nano materials while hydrolysis,acidoge nesis and methanogenesis were only affected by high dose of ZnO The study also attributed the decrease in the rate of biogas production to the released Zn^{+2} ions derived from ZnO [60].

3. Factors affecting Biogas Production

Biogas production is an essential biological process. For this reason, it is necessary to ensure that all conditions are met. To have good results the C / N ratio, pH, ambient temperature, hold time, loading rate, mixing conditions must be completed. An efficient gas production will not take place if all the conditions are not fulfilled. The six main factors affecting biogas yield are: 1. Effect of Agitation on Biogas Yield, 2. Effect of pH of Digester Contents on Biogas Yield, 3. Effect of C: N Ratio on Biogas Production, 4. Effect of Loading Rate on Biogas Yield, 5. Effect of Salinity on Biogas Yield and 6. Effect of Inhibitory Factors and Materials on on Microbial Activity [63].

4. Advantages and Limitations of Biogas Technologies

Renewable energy is the future sustainable green energy. Utilization of biogas reduces global warming, dependency on imported fossil fuels, wastes, and odors full stop it also increases the job opportunities for farmers. moreover It also enlarges the flexibility to use different feedstock and contributes to EU energy and environmental targets. Very few technological advancements have been made or introduced for streamlining and making the process cost effective so, the systems that are currently used are not efficient enough. Hence, even the large scale industrial production of biogas is not shown or visible on the energy map. Most investors are not willing to put in their capital investments in the production of biogas although such investments could be a possible solution to the problems being faced. unfortunate disadvantages of biogas today include the detrimental impact of methane on the climate, the inefficient systems used in the production of biogas and the weak suitability for dense metropolitan areas [64].

5. Drawbacks of Applying Nanomaterials

A disadvantage of bactericidal nanoparticles in general, except for nano-TiO_2, is that no bactericidal substances (such as hydroxyl radicals) remain in the water past the contact time in order to ensure the water quality in storage and distribution devices (depot effect). The stability depends on the essential chemical resistance which is applied to material cleansing. The disadvantages include: less reliability, slow operation process, less selectivity; high maintenance cost and low working efficiency with passage of time. An unfortunate disadvantage of biogas today is that the systems used in the production of biogas are not efficient. There have been no new technologies yet to simplify the process and make it abundant with low cost. This means that extensive large scale production to supply for a large is still not possible enough to meet the needs of a large population [65]

6. Summary and Future Research Needs

Results clearly indicate that using nanomaterials can be a useful strategy to improve the performance of the AD process. Fe, Ni, Co, Mo, Se, Cu, Zn are the main constituents of enzymes/microorganisms and are known to be fundamental trace elements for numerus AD reactions. Depending on type and composition of feedstock, the need for these trace elements is variable. It is crucial to ensure that the proportion of trace elements in AD media is optimal. Deposition of trace elements in form of metal/metal oxide NPs on different supports with optimal proportions is an idea to take advantages of support and deposited materials at the same time to avoid the uneven dispersion of trace elements. Designing multi-functional nanomaterials using trace elements (metal/metal oxide) can increase the bioavailability of the trace elements and strengthen the interaction between NPs of trace elements and functional microorganisms (which are required for AD). In the future, the following points should be considered to achieve a novel multi-functional nanomaterial: (1) Deep understanding of the effects of different nanomaterials on each step of the AD process by using model substrates ,(2) Fabrication of multi-functional nanomaterials, i.e. deposition of several metal/metal-oxide NPs on supporting materials, (3) Tuning the activity of multi-functional nanomaterial via optimization of composition ratios,(4) Assessment of fabricated nanomaterial through application in the presence of different types of substrates [66].

7. Conclusion:

The supplementation of metallic nanoparticles with the AD system presents notable influences on the performance of AD regarding process stability, gas production, and effluent quality. Recently, extensive, especially the ones that are based on trace have pointed out the feasibility of applying some of them that are based on trace on the ground. Nonetheless, the solutions to overcome the hindrances preventing nanoparticles from being used inside anaerobic digesters (such as nano-ZnO, Ag, and CuO) still need further investigations. As for microbial communities, methane producing archaea is more sensitive to the addition of nanoparticles than hydrogen-producing bacteria under the same concentration. The toxic impacts of the metallic nanoparticles on AD microorganisms are dosage-dependent and are largely dependent on their characteristics and fractions of the AD sludge.

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