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Effect of Physical and Chemical Operating Parameters on Anaerobic Digestion of Manure and Biogas Production: A Review

Saeed Samani Majd [1*], *Mohammad Ali Abdoli* [1], *Abdolreza Karbassi* [1], *Hamid Reza Pourzamani* [2], *Masoud Rezaee* [1]

[1] *Faculty of Environment, University of Tehran, Tehran, Iran.*
[2] *Environment Research Center, Isfahan University of Medical Sciences, Isfahan, Iran.*

A R T I C L E I N F O

REVIEW ARTICLE

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Corresponding Author:
Saeed Samani Majd

Email:
ssamnai@ut.ac.ir

Tel:
+989131096130

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ABSTRACT

Introduction: The need for food produced from animal husbandry has made it a growing industry which result in increment of livestock waste. On the basis of environmental and economic considerations, these materials require treatment and management. Anaerobic digestion and creation of biogas are the most effective methods of waste management. Several parameters affect the anaerobic digestion of animal wastes which should be studied in order to optimize the biogas production of reactors.
Materials and Methods: The parameters affecting the performance of anaerobic processes in different scientific databases within 1984 -2016 were searched and related information were obtained.
Results: A wide range of reactors with retention times of 0.5 to 140 days and organic loading rates from 0.11 to 7.5 grams per liter of organic matter in a day were studied based on the Volatile Solid (VS) in different temperature range. Also, studies conducted on mixing, co-digestion, changes in pH and ammonia content of the substrate, C/N ratio, as well as the effect of chemical interference were investigated.
Conclusion: High COD removal decrease of VS were achieved in the range of 80-95 % and 65- 92 % respectively in bioreactors. The produced methane was also 48 mmol L^{-1} to 4681.3 m^3 per month for reactors with a volume of 120 ml to 1330 m^3 achieved respectively at 37 and 55˚C from the Mesophilic and thermophilic temperatures. Results summarized on the physical and chemical conditions in this paper, can be used to study the effective parameters and optimize conditions used in biogas production.

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Introduction

Population increase along with the growing demand for animal food production, have made animal husbandry a growing industry in many countries. This trend results in a great deal of livestock manure, which will have a high environmental impact [1]. Poor manure management leads to adverse environmental conditions such as creating unpleasant odors, attracting rodents and insects, promoting the growth and release of pathogens, surface and underground water pollution, as well as greenhouse emissions such as methane. With stricter environmental rules, more considerations have been intended about livestock manure which led to creation of a requirement in manure treatment and management.

In Poland, more than 2500 million cubic meters of biogas is produced annually, 1022 million cubic meters of which is related to animal manure [2]. Methane produced from different sources in the United States is estimated to be 12040 million cubic meters, from which he livestock manure has a share of 25% in this field [3]. In European Union member states, 1500 million tones of livestock manure is produced annually which amounts to 21000 million cubic meters of theoretically biogas production [4]. Livestock manure in large-scale farms of China is estimated 738 million tons annually which have the potential of producing 47.210 million cubic meters of biogas [5].

In Iran, a strong tendency has emerged to apply renewable energy. Biogas from livestock manure as a renewable and environmentally friendly energy carrier is one of those cases. According to statistics of 2011 there exist more than 72 million livestock in Iran [6], with the annual production potential of 128 million tons of manure; of this amount, 58% is related to heavy animals, 7% to poultry, and the remaining is produced from light animals. Three provinces of Fars, Mazandaran, and East Azerbaijan have the capability to produce more than 7 million tons of manure annually [7]. According to estimates, potential annual production of biogas from livestock manure is 8600 million cubic meters [6, 7]. Mazandaran province with 707 million cubic meters has the greatest potential for production of biogas from livestock manure in country [7].

Anaerobic digestion process

Anaerobic digestion is one of the most effective methods of treatment, in which bacteria in the absence of oxygen decompose and convert food organic matters. Anaerobic digestion process consists of several stages; major phases include hydrolysis, acid-formation, acetate, and methane generation (Figure 1) 8. Anaerobic digestion is a complex process that requires reduction and oxidation potential (ORP) of less than 220 mv and depends on the interaction of microbial activity for conversion of organic matter to CH_4 and CO_2. Hydrolysis Phase converts insoluble organic matter and heavy molecules such as lipids, polysaccharides, and proteins into simple soluble substances such as amino acids and fatty Acids. In the second phase, acid-forming converts material into simpler compounds such as short chain fatty acids. In the third phase, acids and alcohols are degraded to acetic acid, hydrogen gas, and CO_2. In the final phase of methane forming two groups of methane-generating bacteria produce methane in two ways: 1) The first group degrades acetate to CH_4 and CO_2, 2) The second group uses hydrogen gas as an electron donor and CO_2 as an electron acceptor [8].

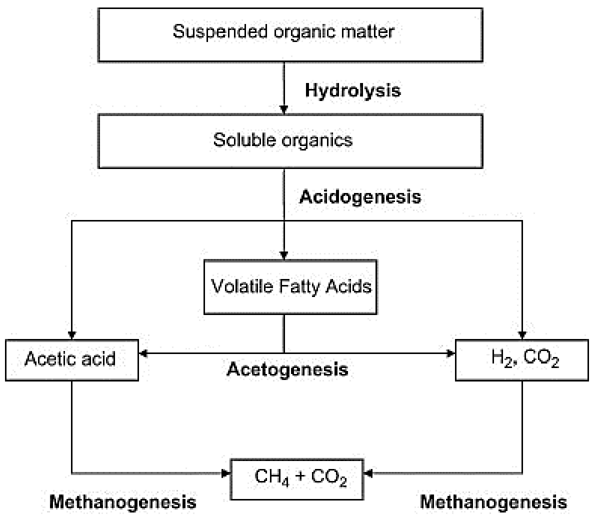

Figure 1: Different phases of anaerobic digestion process

Converting manure to energy through anaerobic digestion is an issue that has been considered in recent years. Efficient production of biogas depends on several factors investigated in several studies. These studies are generally related to digester, operating conditions, as well as the removal and biogas production efficiency. The objectives of this study was to review studies from laboratory scale to field studies on anaerobic digestion of livestock manure to produce biogas, it also aimed to investigate different parameters considered in the study, achieved outcomes, and determine the effective parameters and their efficiency limits in production of biogas and COD removal efficiency. The results of this study can be used in design and operation of reactors with high biogas production and optimization efficiency in both laboratory and industrial scale reactors.

Materials and Methods

All articles used in this study, were of review, laboratory, and field studies which were examined according to the simultaneous key words including Manure, Biogas, and Anaerobic digestion from Scopus database published between a period of 2005 to 2016. On this basis, frequency of the key word Anaerobic digestion was 11323, simultaneous key words of Manure and Anaerobic digestion 1512, and simultaneous key words of Biogas, Manure, and Anaerobic digestion had a frequency of 845. Figure 2 shows the number of researches along with simultaneous key words of Biogas, Manure, and Anaerobic digestion over different years; the graph illustrates the scientific articles in this field over recent years.

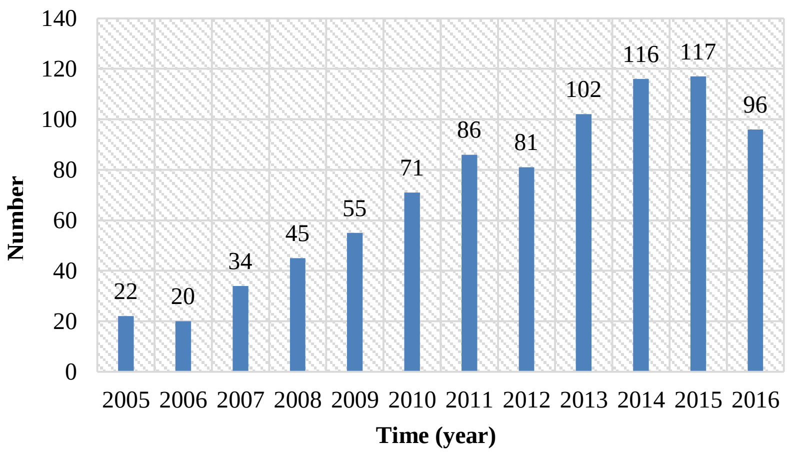

Figure 2: The number of studies conducted during different years (According to simultaneous key words: Biogas, Manure, and Anaerobic digestion in Scopus database) up to December 2016.

Discussion

Several studies have been conducted in different scales on the parameters affecting biogas production process, examining anaerobic digestion process of livestock manure, digester design, and construction, further the removal efficiency and biogas production have been checked. Based on these studies, effective parameters are divided into two categories of physical and biochemical parameters that are described in the following.

Physical Parameters

Temperature

Anaerobic digestion under temperature range is divided into three categories: 1) Psychrophilic (temperature range 10 to 20 ° C), 2) Mesophilic (temperature range 20 to 40 ° C), and Thermophilic (temperature range 40 to 60 ° C) [9]. Since the anaerobic digestion process is entirely dependent on the operations and the balance of bacteria also because most of the population of the bacteria is sensitive to temperature changes, temperature is an important and effective parameter. Bacterial activity decreases with decrease of temperature and digestion rate, in contrast, high temperature makes some bacteria die and thus biogas production decreases [10]. Some studies on anaerobic digestion of animal manure were in the range of Mesophilic and thermophilic (35 ° C to 55 ° C), but some other studies due to the weather conditions around the world evaluated the performance of the process at lower temperatures [11]. During the survey on the anaerobic digestion of pig manure in Guinea, it was shown that low-temperature of 23 ° C had significant effects on biogas production reduction [12]. In a specific retention time of 10 ° C to 23 ° C temperature, there will be a linear reduction in the rate of methane production; in contrast, if in Psychrophilic conditions, organic load is appropriately reduced and hydraulic retention time increases, a high production rate of methane will be achieved [13]. Temperature changes cause a significant change in the process of anaerobic digestion diversity and its microbial population. However, methanogens bacteria in comparison with other bacteria in anaerobic digestion process are extremely sensitive to temperature changes, but in both mesophilic and thermophilic phases they can operate [14]. Mesophilic microbial population in thermophilic phase is completely different, but the same microbes show dynamic changes even in little variations. In 2013 a study on anaerobic digestion of manure in thermophilic phase and in three temperatures of 50, 55, and 60 ° C showed that a temperature of 50 ° C is the optimal condition for the production of biogas. So that removals of 31% VS and 22% LG VS were obtained for production of methane [15]. In 2008, in a study on pig manure in three temperatures of 25, 30, and 35 ° C as well as in four feed loads of 5%, 10%, 20%, and 40% (input volume to digester volume ratio) it was concluded that though with the increase of 25 ° C to 30 ° C the efficiency of methane production in the biogas increased 13%, but an increase in temperature from 30 ° C to 35 ° C will cause no significant changes [16]. Thermophilic anaerobic degradation phase can be up to 7 times faster than that of mesophilic phase, but the belief that storage conditions and temperature in such a situation is costly, has led to less use of it [17]. A study in 2015 on horse manure in two mesophilic and thermophilic phases represents an increase of respectively 58.1% and 59.8% in mesophilic and thermophilic phases of methane production [18]. Furthermore, a study on buffalo manure in two phases of thermophilic and mesophilic showed a double increase in the rate of methane production in the thermophilic phase and 82% share of methane in the biogas [19].

Loading rate of organic matters

In 2002, a study was conducted on UASB reactor performance in pre-treatment of an industrial slaughterhouse's effluent waste water. This test was conducted in a 500-liter pilot of continuous flow inoculated with 200 liters of anaerobic digestion sludge of municipal sewage. In this study, an input COD concentration of 3000-5000 mg/l and loading of 1.8 kg COD per m^3 in 25 degrees in day were considered. As a result, it was reported that there is the possibility of increasing the load up to 14 kg COD per cubic meter in the day and the temperature of 29 ° C with removal of 85-90% of COD. In these conditions, 250 to 300 liter of gas (75% methane) was produced simultaneously with removal of COD [20]. A study in 2012 was conducted on anaerobic digestion of livestock manure and co-digestion of livestock digestion with lignocellulosic constituents in two organic loading rates of 1.5, and 2.6 VS/L.d in mesophilic conditions inside continuously stirred tank reactors (CSTR). Results in both situations (livestock manure digestion and co-digestion) showed a reduction in methane production which was attributed to the accumulation of inhibitors and recalcitrant solids [21].

Mixing

Mixing in anaerobic digestion process accelerates the process by exposing substrate material with bacteria and also by homogeneous temperature distribution. Mixing can be done either mechanically or by recycling of produced biogas. In 2007, a study was conducted to investigate the effect of mixing in three conditions of continuous, minimum, and intermittent in a laboratory scale on methane production. The results showed 12% of methane increase in minimal mixing conditions [22]. In 2015 a study was conducted to investigate the effects of mixing on digestion of livestock manure and produced biogas using one- liter closed reactors. In this study it was reported that mixing prevents production of biogas and the results showed lack of transfer from acid formation phase to methane generation phase. Finally, it was concluded that parameters' mixing depends on other physical and biochemical parameters of substrate. It is also different about different reactor types and manures and must be determined according to local conditions [10].

Co-digestion of organic materials

Many studies in recent years over anaerobic digestion have been focused on co-digestion. Co-digestion means digesting two or more substrates simultaneously; this is one of the most common strategies to overcome difficulties and restrictions with anaerobic digestion of a specific substrate material. In many Co-anaerobic digestion studies, livestock manure was considered as the main substrate, further, to promote the process of digestion, other materials such as activated sludge, municipal organic waste, agriculture waste, and so on were used. [23]. Figure 3 shows the studies carried out in the field of anaerobic digestion according to simultaneous key words of manure, co-digestion, and anaerobic digestions in Scopus database. Also, it illustrates consumed substituted substrates along with livestock manure in 2016. Accordingly, agricultural and industrial wastes have been receiving serious attention to be co-digested with livestock manure. Additionally, organic wastes such as food waste byproducts of biodiesel production from microalgae have been considered in recent years. Also figure 4 illustrates the distribution of common substrates used with animal wastes in researches of 2016.

Co-digestion of animal manure and agricultural manure can increase biogas production in several ways: 1) Help to maintain the optimum pH for methane production, 2) Reduction of ammonia's inhibition that may occur in the digestion of manure plant, 3) Providing the proper ratio of carbon to nitrogen [24].

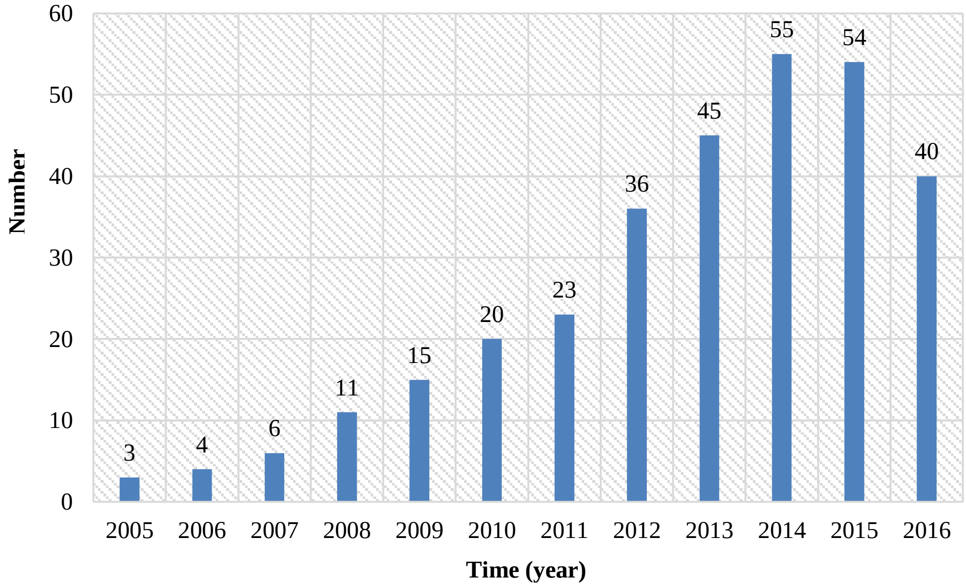

Figure 3: Frequency of studies conducted during recent years (according to simultaneous key-words of anaerobic digestion, co-digestion, and manure in Scopus database) up to December 2016.

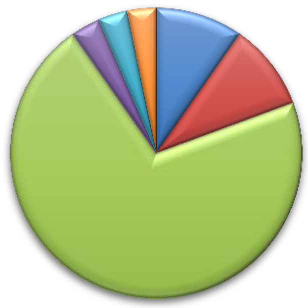

Figure 4: Distribution of common substrates used with animal wastes in researches of 2016

Ammonia

Ammonium ions NH_4^+ and free ammonia NH_3 are two main forms of inorganic nitrogen ammonia. Ammonia concentration is one of the basic parameters in the process of anaerobic digestion and methane production. Although, ammonia is a nutrient for bacterial growth, in high concentration it can prevent from the growth of anaerobic digestion process [25]. Ammonia nitrogen-containing materials are produced through biological degradation. Inhibitory process is totally dependent on other parameters in anaerobic digestion process, such as temperature, pH, and type of seed sludge reactor structure, as well as ammonia and ammonium concentrations [26]. Various studies in recent years have examined the effects of ammonia on anaerobic digestion performance. Methane-generating hydrogen-consuming bacteria are quite sensitive to ammonia nitrogen [27]. Concentration of 150 mg/l of free ammonia may have high inhibitory effects on anaerobic digestion, although this issue depends completely on other conditions such as loading of organic matter, pH, etc. Basically, if concentration of bacteria gradually increases in the digester, they can even adapt to concentrations of 5000 g/l [26]. Anaerobic digestion materials that are rich in nitrogen, such as livestock waste, result in high concentrations of ammonia in the sludge; ammonium integration leads to increased concentration of short-chain fatty acids and decreases the pH [28]. In such a situation, the destruction of organic materials is slowed, methane production rate decreases, fermentation conditions become unbalanced, and finally unpleasant odors will be felt around the biogas production plant [29]. In a study carried out by Cao et al. in 2013 on anaerobic digestion of animal waste, it was shown that ammonia and humic acid have inhibitory effects on methane production [30]. In a study in 2016 on the simultaneous digestion of poultry manure and corn waste, it was represented that due to high concentrations of nitrogen in percentages higher than 20%, the ammonia nitrogen will be greater than 7 g/l, fatty acids will be concentrated, and methane generators at higher concentration than 9 g/l will become completely inactive [31].

C/N Ratio

Biogas production is directly related to the type of material entering the reactor, one of the most important parameters in this case is the ratio of carbon to nitrogen. Gripentrog et al. reported that high ratio of carbon to nitrogen causes a very high population growth in mutagens, while they meet their protein needs, but do not consume carbon more than that and this issue leads to reduction of gas production. The authors reported that if this ratio is low the amount of ammonia will be increased and environment for the growth of methane generating bacteria will become toxic, therefore optimum carbon to nitrogen ratio of 20 to 30 was suggested

[32]. The ratio of carbon to nitrogen in livestock and poultry wastes is from 4 to 6, while the suitable ratio for anaerobic digestion process of 13 to 28 has been determined [33]. Wang et al. conducted a study on the effect of carbon to nitrogen ratio on co-digestion of animal manure and straw in two phases of thermophilic and mesophilic. They show that the C/N = 15 in phase mesophilic and 20 in thermophilic phase have inhibitory effects on methane production. The maximum methane produced in C/N will be achieved as 25 and 30 in two phases of Mesophilic and thermophilic, respectively. These results suggest an interaction between temperature and carbon to nitrogen ratio on anaerobic digestion process performance [34]. In a study in 2012 on co-digestion of livestock, poultry, and wheat bran manures, it was reported that C/N ratio in the range of 25 to 30 has a stable pH and can be inhibitory at least in methane production. Also, optimum ratio of 27.2 was suggested [35].

pH

Methane generating bacteria in the process of anaerobic digestion are very sensitive to acid conditions and their growth stops in acidic conditions. The optimum pH for anaerobic treatment is 5.5-8.5. Good acidity for Methane generating bacteria is 6.5-7.8, while for acid-forming bacteria it is 5-6. For proper growth of anaerobic microorganisms and sludge seeds, optimum pH is in the range 6.5-7.5 [36]. Zhai et al. examined the effects pH co-digestion of animal manure and food waste, they observed that the greatest amount of methane production was achieved at pH = 7.5, also in these circumstances the phase delay decreased significantly compared to pH 8 and 7 [37]. In a study in 2015 on co-digestion of animal manure and corn waste, it was indicated that pH has a high effect on the performance of anaerobic digestion process, and the maximum amount of biogas production is 146.32 mL/g VS at pH = 6.8 and share of livestock manure is 70% [38].

Antibiotic

In 2006 an ASBR reactor on a laboratory scale was used to treat a mixed substrate which had a medicinal swage with loading rate of 2.9 grams COD in liter per day. After reaching the equilibrium, the reactor was exposed to a low amount (1 mg/l) and high amount (200 mg/l) of antibiotic erythromycin. Small amounts of this substance reduced gas production, but its high amount did not have any effect on the production, which represents the resistance of bacteria to antibiotics [39]. In 2012, the effects of antibiotics extetrasilin, tylosin, and amoxicillin on wastewater treatment process were examined. The results showed that with increasing concentrations of antibiotics, volume of produced biogas from biomass per weight unit will be reduced [40].

Hydraulic detention time and reactor type

One of the parameters affecting production of biogas is hydraulic detention time, which is different and broad depending on the type of processes. Since hydraulic detention time depends on the type of reactor and reactor forms the process, thus reactor type determines hydraulic detention time [10]. A broad range of reactors such as fixed-film reactor, attached-film bioreactor, anaerobic rotating biological reactor, batch reactors, down flow anaerobic filter, fixed dome plant, up flow anaerobic sludge blanket, continuously stirred tank reactor, up-flow anaerobic filter, temperature-phased anaerobic digestion, anaerobic hybrid reactor, and two-step system to optimize the production of biogas, and anaerobic biodegradation organic have been employed, which will be discussed below.

In a study, fixed film digester performance with a volume of 4 liters at a temperature of 30 ° C with periodic mixing was studied. In this study it was concluded that the maximum methane production per day for fixed film reactor by loading 672 g VS L^{-1} is 6.33 liters which is obtained in the hydraulic retention time of 1 hour [41]. In other studies, animal sewage digestion was examined through using filtered down-flow anaerobic reactor with ceramic rings. In this study by applying the detention time of 0.5 to 4 days, soluble COD removal rate was reported as 55-87% [42].

In 1996, performance of four anaerobic reactors (CSTR, UAF, UASB, and walled reactor) in diluted wastewater treatment was examined. In this study it was reported that with hydraulic detention time of 2 to 18.8 days with organic matters' loading rate of 0.117 to 1.103 g VS L^{-1} per day, SS and COD wastewater parameters in UASB and UAF reactors that have walls have reached the standard limit with respective hydraulic detention times of 3, 4, and 5 days [43].

In a research in 2002, anaerobic livestock manure treatment in thermophilic temperature in UASB reactors with 9 liter volume was conducted. In this research the highest percentage of COD removal (79.7%) in hydraulic detention time of 22.5 days was obtained [44]. In a study on a two-phase anaerobic reactor, it was reported that separation of acid-forming and methane generating digest phases leads to a significant increase in the maximum rate of methane production and the maximum methane rate at the detention time of one day for fixed film reactor will remain fixed [45]. In another study a contact anaerobic rotating biological reactor was tested in mesophilic temperature (35 °C). In this study, 5.5 liter reactors with 3% VS and detention time of 1-11 days were examined. Maximum biogas production was 1.89 L CH_4L-1 in one day and 0.093 L CH_4 g^{-1} VS in 11 days. The authors reported that this type of reactor is more efficient than fixed film reactor [46].

In 2004, a laboratory study was carried out to compare two-step digestion by two-step digesters with volumes of 0.6 and 2.4 liter in under 68 and 55 degrees with detention times of 3 and 12 days with one-phase reactor under 55 degrees and hydraulic detention time of 15. In both studies, both systems had loadings of organic matters 3gVS $L^{-1}day^{-1}$. The authors found that the two-step reactor has 6 to 8% higher methane production and a higher removal of VS compared to one-step reactor [47].

In 2015, anaerobic digestion of livestock manure in reactor type AHR with effective size of 14.5 liters of recycled biogas was examined. The reactor was measured at seven different time periods. The authors reported that mean value of produced methane was higher than previous time. This indicated that an AHR reactor with floating media can have high output for fixation of biomass and recycling of biogas in anaerobic digestion of livestock manure in high concentration and loading [48].

In a study on anaerobic digestion basic temperature (TPAD) system, two cylindrical reactors made of Plexiglas with a one-stop thermophilic (38°C) and mesophilic (58°C) temperatures with volumes of 12 and 18 liter in a hydraulic detention time of 4 and 10 d were examined. Reactors were seeded with activated sludge of a thermophilic laboratory reactor and a mesophilic large-scale reactor. This TPAD system had six substrates with different characteristics. In this study the maximum removal value was 42.6 VS % and methane obtained with optimum loading of organic matters was 0.54 – 0.61 L CH_4 g^{-1}VS [49].

Effectiveness of reactors with additional film psychrophilic digesters was investigated. In this study, eight 5-liter digesters with temperature range of 10 - 37 °C with a variety of media of polyester and lime were tested. It was reported that polyester media type with high porosity and high surface to volume ratio has the best performance in the production of methane at a temperature of 37 °C [50].

Determining biogas digester volume

In 2004, the method of determining volume in digestion process of a fixed dome plant was examined. In this study one Kg of livestock manure with equal amount of water in the reactor with a volume of 0.002 m^3 were loaded. Then, 35 to 40 liter of gas at a hydraulic detention time of 55 to 60 days in an average temperature of 24 to 26 °C was produced. This study reports that for a continuance daily feed rate of average 25 Kg animal manure, digester needs to have a volume equal to 2.75 to 3 m [3, 51].

In 2005 a group of researchers in Denmark provided some necessary calculations for biogas plant design. They designed a digester for 9.23 tons substrate per day. The mixing ratio of manure with water was 1 to 2 and hydraulic detention time was 60. According to given parameters, digester volume was determined as 1300. The biodegradable materials existing in organic deposits was 13 % , average gas production was equal to 0.2 m_3 kg^{-1} VS, and gas production of 7202 m^3 per months was obtained [32].

Table 1 shows a summary of studies conducted on physical parameters and biogas production productivity from manure.

Table 1: Summery of studies conducted on physical parameters and biogas production productivity from manure

Feed stocks	Reactor type and volume	Input rate	Detention time (day)	Temperature (°C)	Productivity removal (%)	Biogas production
Livestock manure	UASB 9 L		7.3 to 22.5	55	79.7	
Livestock manure with glycerol triemil	Two laboratory-scaled reactors	3 g VS per liter per day manure	15	37	37 % VS	224 ml methane per g VS per day
		4g VS per liter per day manure+2 percent GTO	15	37	51 % VS	382 ml. methane per g VS per day
Livestock manure	Two-stem digester (55 and 68 degrees) and (0.6 and 2.4 liter volme) manure	3 g VS per liter per manure	12 and 3	68 and 55 degrees	49.9 % TS and 47.1 % VS	260 ml methane per g VS per day
Livestock manure	Fixed dome reactor, 1-2 cubic meter	20 to 25 in cubic meter Kg per day	55 to 60	24 to 26 degree		35 to 40 liter biogas/ (1:1)
Livestock manure	Field biogas reactor, 1300 cubic meter	9230 Kg feedstock per day	60	Internal temperature		7202 cubic meter biogas per month (65 % methane)
Manure	14.5 liter	7.3 g VS per liter per day	15	36	48 to 68 COD 64 to 78 % BOD	0.191 liter methane per g VS
Manure	Octet bioreactor 5L	0.12 Kg VS per cubic meter per day	33	10 to 37	79 to 94 % removal COD	0.45 cubic meter biogas per Kg
Manure	Mixing and non-mixing reactors (0.6 and 2.4 liter volume)				7.3 and 9.6 % VS(mixed and unmixed)	0.2 cubic meter biogas per VS kg
Manure	UASB Reactor		22.5		75 % COD	0.2 to 0.39 cubic meter biogas in kg COD
Manure	Lab, 3 liter	3 gram VS per liter per day	15	55 and 65 degrees		165 to 202 ml methane in g per day (55 and 65 °C)
Manure	Lab, 12 and 18 liter	5.82 gram VS per liters per day	4 and 10	38 and 58 degrees	42.6 % OCD 64 to 78 % BOD	0.54 to 0.61 liter methane per g per day

Economic analysis

One of the challenges facing biogas plants is relevant production costs. These costs include the cost of land, labor, transportation, transportation, maintenance, management, storage, and initial costs (machinery and equipment) industry. In the case of livestock manure since the disposal and purifying imposes considerable material costs, costs of biogas production can be negative or zero. From socio-economic perspective, co-digestion of organic waste and manure can have many advantages, because of reducing production cost, waste treatment costs, activity of pathogens, removing unpleasant manure odor, and greenhouse gas emissions [52]. Kavinato et al. conducted a study on thermophilic digestion of livestock manure, agricultural, and industrial wastes. These three investigations were carried out separately but simultaneously. Researchers showed that the return on capital for co-digestion will be 2.5 years, for separate manure digestion 3 years, and for anaerobic digestion along with nitrogen treatment it will be 5 years [53]. On the other hand, biogas has a specific impact on economic justification. In a study in 2005 in Denmark it was showed that if the yield is higher than 32 cubic meters per ton, anaerobic digestion biogas waste would be economical [54]. Gebrezgabher et al., investigated different scenarios of anaerobic digestion of manure with food and agricultural waste, they showed that all options, except the absence of subsidies, have economic feasibility. Further, it was showed that issues of transport impose the highest costs [55]. In a comparison in 2015 among anaerobic co-digestion of manure, food waste, anaerobic digestion of manure, and landfill food waste, net energy production ratio in the first option was found to be 1.67 times higher than the second one. Also, 25-year net profit of the first option was about 8.4 million dollars compared to that of 7.5 million dollar cost of second option [56]. Also some of researcher have tried to modify the process by stimulating the bacteria in order to increase biogas yield which one of these researches worked on electrobiochemistry and increased biogas by 10%.

Conclusion

Anaerobic digestion of livestock manure management is a viable option. Most of the studies carried out on anaerobic digestion of animal manure, have investigated various types of reactors in a wide range of physical and biochemical parameters. Physical parameters include hydraulic retention time, temperature, mixing, loading rate of organic materials, and simultaneous digestion of organic matter. Biochemical parameters consist of carbon to nitrogen, ammonia, pH, and the interaction of chemical waste.

Studies indicated successful performance of anaerobic digestion at mesophilic temperature of 37°C and thermophilic temperature of 55°C. Produced biogas or methane depends on the reduction of VS and COD as well as reducing both packages on the type of utilization. In literature a wide variety of reactors was studied most of which were performed on laboratory scale and a few on the actual scale.

Another important consideration is environmental benefits and economic value. Surplus waste means high shipping costs and time loss. For such cases the use of small-scale biogas technology seems very logical.

The optimal ratio of carbon to nitrogen is 30:1, which to supply population growth of methane generating bacteria depending on type of injected fertilizer into the reactor needs to be supplied. These low levels of this ratio limit methanogenic bacteria activation and reduce gas production.

The optimal pH should be in the range of 6.2 - 8.5 to accelerate granular sludge growth and stimulate response activities of methane generating bacteria. Too much increase or decrease in the amount of pH has harmful effects on the performance of the reactor that is due to inhibitory property of methane generator bacteria. Co-digestion of several types of manure mixed with each other or with other materials could lead to an increase in methane production. Seeding with activated sludge digester picked from Mesophilic and thermophilic digesters while working is strongly recommended to enhance the digestion process efficiency. Especially, cultivation with mature crops biomass requires less start-up time and leads to faster bio-degradation of waste.

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Conflict of interest

We have no competing interests.

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