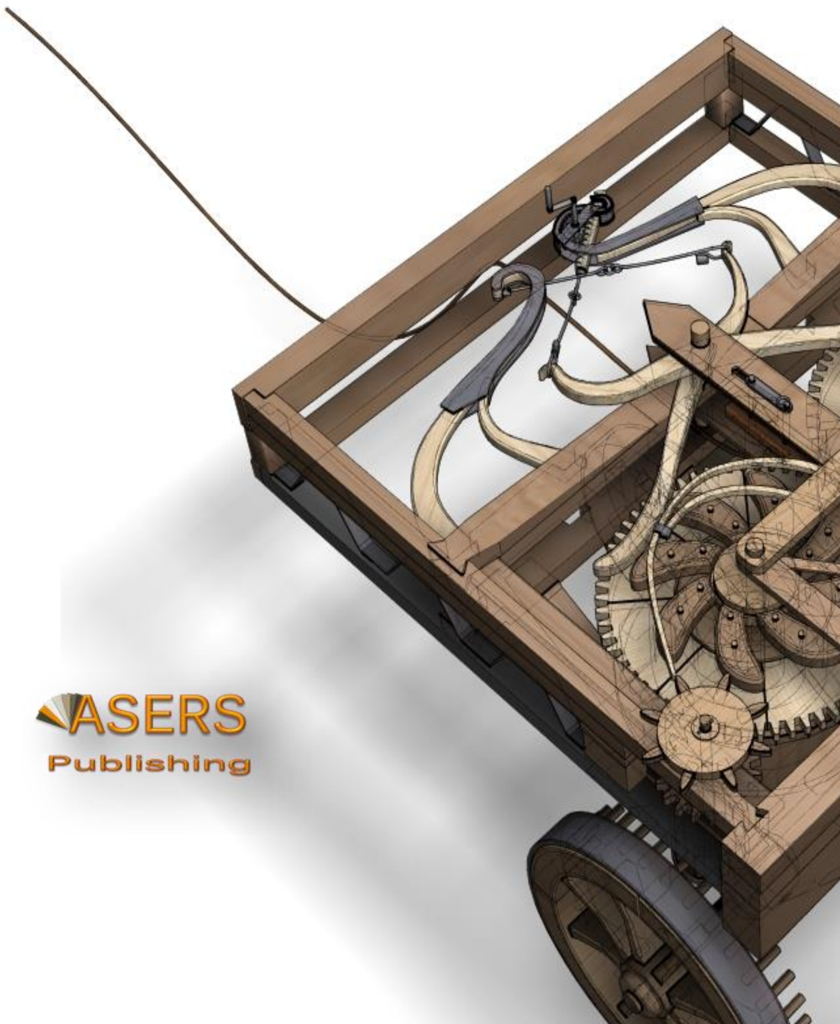
ASERS

Journal of Environmental Management and Tourism



Quarterly
Volume XIV
Issue 1(65)
Spring 2023
ISSN 2068 – 7729
Journal DOI
https://doi.org/10.14505/jemt

ASERS Publishing

Spring 2023
Volume XIV
Issue 1(65)

ASERS Publishing
http://www.asers.eu/asers-publishing
ISSN 2068 – 7729
Journal DOI: https://doi.org/10.14505/jemt

Table of Contents:

Spring 2023
Volume XIV
Issue 1(65)

ASERS Publishing
http://www.asers.eu/asers-publishing
ISSN 2068 – 7729
Journal DOI: https://doi.org/10.14505/jemt

Call for Papers
Summer 2023 Issues
Journal of Environmental Management and Tourism

Journal of Environmental Management and Tourism is an interdisciplinary research journal, aimed to publish articles and original research papers that should contribute to the development of both experimental and theoretical nature in the field of Environmental Management and Tourism Sciences.

Journal will publish original research and seeks to cover a wide range of topics regarding environmental management and engineering, environmental management and health, environmental chemistry, environmental protection technologies (water, air, soil), pollution reduction at source and waste minimization, energy and environment, modeling, simulation and optimization for environmental protection; environmental biotechnology, environmental education and sustainable development, environmental strategies and policies, etc. This topic may include the fields indicated above, but are not limited to these.

Authors are encouraged to submit high quality, original works that discuss the latest developments in environmental management research and application with the certain scope to share experiences and research findings and to stimulate more ideas and useful insights regarding current best-practices and future directions in environmental management.

Journal of Environmental Management and Tourism is indexed in SCOPUS, RePEc, CEEOL, and ProQuest.

All the papers will be first considered by the Editors for general relevance, originality and significance. If accepted for review, papers will then be subject to double blind peer review.

Deadline for submission:	21st April 2023
Expected publication date:	June 2023
Website:	https://journals.aserspublishing.eu/jemt
E-mail:	jemt@aserspublishing.eu

To prepare your paper for submission, please see full author guidelines in the following file: JEMT_Full_Paper_Template.docx, then send it via email at jemt@aserspublishing.eu.

DOI: https://doi.org/10.14505/jemt.v14.1(65).07

Biofuel Production from Animal Waste in Northeastern of Libya: Experimental and Simulation Investigations

Monaem ELMNIFI
Faculty of Engineering Technologies, Bright Star University, Libya
monm.hamad@yahoo.co.uk

Abdelnaser OMRAN
Faculty of Engineering Sciences, Bright Star University, Libya
naser_elamroni@yahoo.co.uk

Magdi ALMOSMARY
Higher Institute of Agricultural Technology, Libya
magdi.almosmary@gmail.com

Rahel G. RAHEL
Faculty of Engineering Sciences, Bright Star University, Libya
rahelmar@yahoo.fr

Suggested Citation:

Elmnifi, M., Omran, A., Almosmary, M., Rahel, R.G. (2023). Biofuel Production from Animal Waste in Northeastern of Libya: Experimental and Simulation Investigations. *Journal of Environmental Management and Tourism*, (Volume XIV, Spring), 1(65): 67 - 81. DOI:10.14505/jemt.v14.1(65).07

Article's History:

Received 4th of November 2022; Received in revised form 6th of December 2022; Accepted 12th of January 2023; Published 10th of March 2023.

Abstract:

The increasing energy demand and the associated environmental pollution have attracted research in renewable energy production from organic resources and waste. Renewable energy resources can reduce greenhouse gas emissions and contribute to energy security. Anaerobic digestion (AD) is an environmentally friendly and effective technique for producing biogas from biomass. This biogas can be used to generate electricity, produce process heat and other energy uses. The Aspen Plus simulation model was used for the AD process for biogas production in this work, with an experiment for anaerobic digestion tank design. The effects of temperature and hydrogen flow at work, the acid content of raw materials, and the operating pressure on biogas production products were analyzed and optimized. The optimum production level for biomethane was 75 liters at the feed flow rate of 20%, a hydrogen flow rate of 180 liters/day, the pressure of 2.5 bar, pH value of 7, and the operating temperature value of 50°C.From the experiment, the results indicated that biofuels could be produced with a cumulative rate of 564.3 m^3 and a daily production rate of 18.81 m^3 from animal waste.

Keywords: Aspen Plus simulation; anaerobic digestion; biogas; methane.

JEL Classification: P18; P28; Q16; Q24; Q53; Q55; R11.

1. Introduction

The increasing demand for energy and the sustainability of its resources remains one of the most critical problems in the world today for energy. Currently, fossil fuel is the main source of energy globally and this has contributed immensely to environmental pollution. There are many possibilities for harnessing energy from renewable sources. This could significantly reduce the environmental pollution caused by municipal solid waste, which affects the food, groundwater, and industries that depend on these resources. Due to global demand, fossil fuel import and export have significantly impacted both national and international security (Moriarty 2013). Hence, efforts are needed towards the development of technologies for the production and use of sustainable energy to meet the ever-increasing energy demand and address some of the negative impacts of over-reliance on fossil fuel for energy generation. One of the ways of producing renewable biogas is through anaerobic digestion (AD); this technique makes efficient use of waste materials, such as wastewater and solid waste as the starting material. Anaerobic digestion refers to the bio-decomposition of organic materials using microbes in an oxygen-deficient environment; the organisms facilitate the conversion of the complex organic materials into free and soluble monomers, giving off carbon dioxide and biomethane as waste products. Biogas can be used for many purposes, such as cooling, heating, and power generation as it contains about 30% carbon dioxide and 70% methane. Biogas can also be used as an alternative to natural gas in most equipment even though it is lower in energy value than natural gas (Lim 2011; Deublein and Steinhauser 2011). Table 1 presents the typical composition of biogas (Lusk 1998).

Table 1. Composition of biogas produced via anaerobic digestion

Element	Chemical Formula	Composition%
Methane	CH_4	50-75
Carbon Dioxide	CO_2	25-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0 -1
Hydrogen Sulfide	H_2S	0 -3

Source: Hammoud *et al.* (2014)

Since the 18th century, anaerobic digestion has been the most adopted technology in India. AD found application later in the United Kingdom where it was used to produce fuel for streetlamps. Owing to the energy value of biogas, scholars have continued to quantify the volume of biogas that can be produced from organic materials and wastewater. Anaerobic digestion has been used worldwide to treat wastewater due to its efficiency in bio-waste conversion to green energy (Cho & Young 2018). Many countries have over the years developed and modernized AD for large-scale application. Some conventional systems included a conventional molded tank, a mixing tank to control the temperature and distribute the organic materials inside the tank (Noonari *et al.* 2019). Another more advanced design contains an internal medium that acts as the reactor for anaerobic digestion (Guerini Filho *et al.* 2019). These systems are also classified by the feeding process that is inserted into the tank.

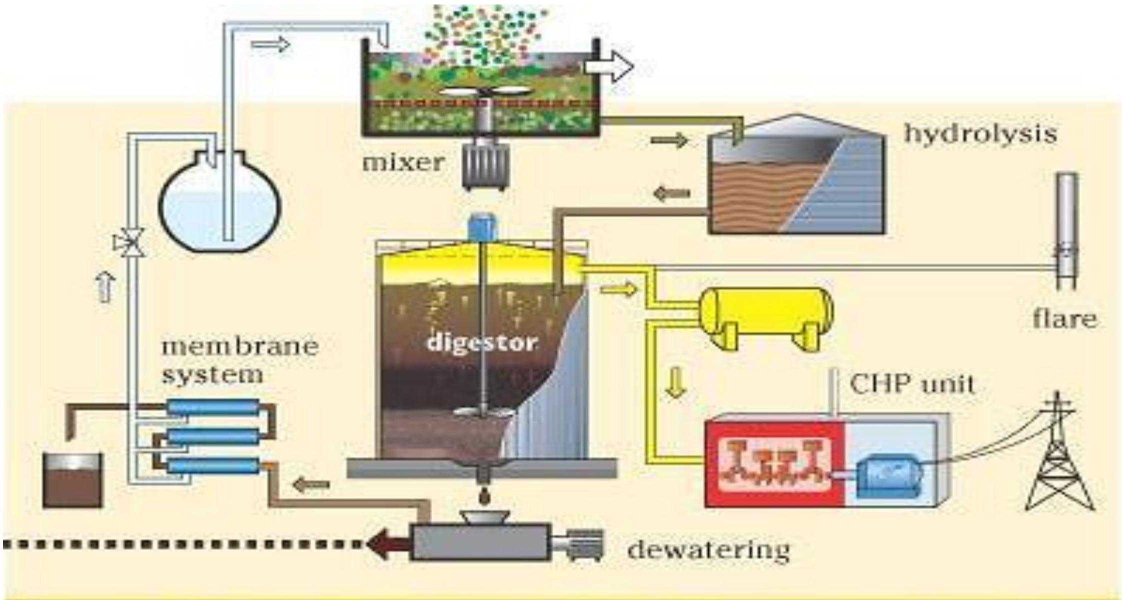
1.1. Waste-To-Energy Technologies

The available technologies for domestic solid waste management include pyrolysis or gasification, burning with energy recovery, derived fuel (RDF), plasma arc gasification, and anthropogenic/human digestion. Bio-methanation is the process of converting the organic components of solid municipal waste into bio-methane (Clark and Rogoff 2010). Although the starting materials for bio-methanation may differ, studies have shown that they mainly consist of agricultural waste, whey, vegetable market waste, restaurant waste, and dairy waste (Greater London Authority 2008; Chakraborty *et al.* 2013). Bio-methanation has an estimated conversion efficiency of about 25% (Malakahmad *et al.* 2012) but its major disadvantage is that it requires a large space. The raw material (collected waste) must be well covered to enable anaerobic digestion and must not be opened for some years, thereby making that occupied space unavailable for other uses within the next few years (Samuel *et al.* 2006). This has been the limiting factor to its implementation in urban areas.

1.2. Anaerobic Digestion Process

The term biomass refers to organic waste which could be human, animal, and plant waste. It may be solid, such as garbage, animal, and tree waste, and it may be liquid, such as sewage and waste of some industries. Methane is produced from animal waste by a method called anaerobic digestion. The exploitation of biomass is imperative because it is polluting the environment and must be properly managed to ensure public health safety; this can be achieved through biomass conversion to energy or recycling. Benefiting from animal waste is not a new thing. At the simplest level, animal waste can be used to produce energy by burning it directly (Metro Waste Authority. 2012-2013). Now that the world lives and is obsessed with depleting fossil energy sources with higher prices than they were, interest in animal waste as an energy source has been rekindled, as this waste will become a saving source when used to produce methane gas. Among the elements that contain animal and organic waste are carbon and hydrogen remain the major components of most standard fuels but as for nitrogen, it is what plants need, and accordingly, the organic waste works as a source of energy and fertilizer for plants at the same time. Using organic waste as fertilizer only means wasting energy available in it, which can be obtained easily. AD is the process of decomposing wet organic matter from plant or animal sources by microbes in an oxygen-deficient environment. This microbial process produces methane (CH_4) and carbon dioxide (CO_2) as waste products in a mixture range of 50-75%, respectively. Stable residues called biogas fertilizer are also left out during the process; this fertilizer contains all the nutrients of the fermented waste (see Figure 1 for more details) (Gotmare *et al.* 2011).

Figure 1. Anaerobic digestion process



The organic waste is placed in a digester (oxygen-free) for the microbes to digest; the digestion process produces a mixture of CH_4, and CO_2 called biogas. After the digestion process, natural treated fertilizer is left over as a liquid. The gas produced from the microbial process is channeled to a storage tank; the volume of the produced gas is equivalent to 1.5-2.5 folds of the digester size. The ratio generally ranges from 60-70%, the remaining waste after bioconversion mainly contains nitrogen and is used as fertilizer. So, anaerobic digestion converts solid and liquid waste into biogas (for energy production) and organic fertilizers (for plant growth). Cow dung is the most considered waste for biogas generation, and it is produced in large quantities in Libya due to the number of cows in the country (Hamilton, 2012).

1.3. Rate of Biowaste Generation in Libya

Municipal solid waste (MSW) data in Libya was collected for the period of 2012–2030. The MSW percentage per capita in 2006 and 2010 was around 0.915 kg/day and 1.1 kg per day, respectively (Gebril *et al.* 2010; Omran *et al.* 2011; Omran *et al.* 2008; Omran and Gebril 2018). In the Middle East and North Africa, MSW generation is estimated at around 0.16 to 5.7 kg/person/day, with an average value of 1.1 kg/capita/day. However, this study was based on 1.3 kg/person/day as calculated from the work of previous studies. Table 2 presents the technical data for MSW potential for Libya (Elmnifi *et al.* 2018; Elmnifi *et al.* 2017).

Table 2. Municipal solid waste data of Libya from 2012 to 2030

Year	Citizens [pears]	Waste indicators [kg/pres/ day]	Waste quantity [kg/pres/ day]	Waste quantity [ton/year]	The cumulative amount of waste
2012	5878100	1.3	7641530	2789158	2789158
2015	6759815	1.3	8787759	3207532	5996690
2020	7773787	1.3	10105923	3688325	9685015
2025	8939855	1.3	11621812	4241665	13926680
2030	10280833	1.3	13365083	4878225	18804905

Source: Elmnifi *et al.* (2018) & Elmnifi *et al.* (2017)

2. Scope of the Study

The work presented in the paper was based in Al-Marj city, shown in Figure (2). It is a city located in the part eastern of Libya (Coordinate 32.495865, 20.827179), 15 kilometers from the sea and about 100 kilometers from the second-largest city in Libya, Benghazi. The city has agricultural topography, which makes it a first-class agricultural city.

Figure 2. Al-Marj city location

The bio-methanation technique was considered and experimented with, and this technique was chosen based on its low capital cost (tons/year), net operating cost per ton, technology simplicity, and higher efficiency compared to plasma arc gasification, pyrolysis, and burning [9,10]. Additionally, this work presents the Aspen Plus simulation of organic waste to generate biogas by simulation the AD process of on cow, sheep, and chicken waste to produce biogas.

3. Experimental Investigation

MSW has significant economic potential as an energy source when the price of conventional fuels (oil and coal) increases (Chen and Neibling 2014). The previous research showed that organic waste constitutes 56% of Libyan cities' total waste (Hamilton 2009). They are disposed of by random burning or left in open landfills. Therefore, local municipalities must manage waste in modern ways, such as for energy generation. New technologies can increase the efficiency of converting waste into energy and preserve the environment. The suitable locations have been identified for the study area to provide the appropriate temperature (23-30°C). Farm animals such as cows and chickens are available as a prerequisite for creating biogas as they abound in rural farms in the Alawailiya area.

3.1. Biogas Production Unit Design

Experimental work was done based on the techniques described above and run for 30 days. The experimental setup consists of the following:

- External tank.
- Internal tank.
- External tank base.
- Entrance to organic waste, including chopper.
- Gas outlet installations, compost outlet, and cleaning outlet.

The necessary openings were made with the outer and inner tanks as in Figure 3. Then, the outer tank was placed on the metal base as in Figure 4. Stones were placed on the floor of the outer tank as shown in Figure 5.

Figure 3. Openings inside and outside of the tanks

Figure 4. Placement of the outer tank on the metal base

Figure 5. Pebbles used on the floor of the outer tank

The necessary tubes (gas outlet, manure, and the waste insertion tube with the chopper and the cleaning hole) were connected as shown in Figure 6. Half of the outer tank was filled with organic waste and water at a rate of 1:1 (the organic waste includes cow dung and chicken waste) as in Figure 7, starting with the daily filling of organic waste of about 10-12 kg/day and water at a rate of 1:1.

Figure 6. Installation of the necessary pipes

Figure 7. Organic waste filling half of the outer tank

3.2 Operation of the Biogas Production Units

A mechanical mixer was designed with a height of 35 cm from the base of the biogas production unit, 15 cm in diameter, and a fan length of 20 cm, rotating at a speed of 35 revolutions per minute and works for 5 minutes per hour to provide a good suspension for the methanogen. The homogeneous temperature of the solution broke the slag layer formed on its surface. Pressure gauge test: After filling the room with water, the pressure in the tube on the pressure test plate (manometer) increased and leaves for 12 h; then, the pressure was measured for the water again. Whenever the pressure is at the same level (water column), the unit is intact from leakage. If the pressure drops to more than 6 cm in the manometer, this indicates a leakage, and it is treated immediately by raising or lowering the first cap of the unit. To prepare the solution as the starting principle of the anaerobic fermentation process at pH = 7.6 and increase the reaction velocity, the unit was filled with animal wastes, followed by water to a total solid matter concentration of 8%. The amount of heat required to raise the temperature of the solution and the pH of the mixture was determined. The ratio of methane and carbon dioxide was in the biogas was determined using a CO_2 tester as in Figure (8). The biogas produced from the production unit was collected in internal car tires as shown in Figure (9).

Figure 8. CO_2 tester

Figure 9. Gas storage

4. Results

This research summarized the production of biogas from animal waste via the AD process using a custom-made reactor; local materials were used to produce the bladder gas and fertilizer. The analysis of the material leftover from the fermentation process (compost) indicated its richness with the essential nutrients for plants, and the ratio of carbon to nitrogen was 14.9. The pH of the solution after the experiment was 8.2. Figure (10) showed the daily gas production during the fermentation period of 30 days. The results showed that the biogas production rate started at 8 m^3 on the first day and steadily increased to 39 m^3 on the 13^{th} day. After that, it almost linearly decreased to 3 m^3 at day 30. Figure (11) showed the cumulative production of biogas over 30 days (survival time) at 564.3 $m^{3,}$ and the average daily gas production was 18.81 m^3 per day. Figure (12) showed the methane content of the biogas during the fermentation period. The results indicate a decrease in the methane ratio in the first days of the fermentation process. The methane ratio was low during the first two days of fermentation, and the figure showed the minimum and the maximum content of methane in the produced biogas as 54% and 72%, respectively, with an average of 66.3%. A medium burner was fired for 9.4 h using 1 m^3 of the resulting biogas.

Figure 10. Daily production of biogas

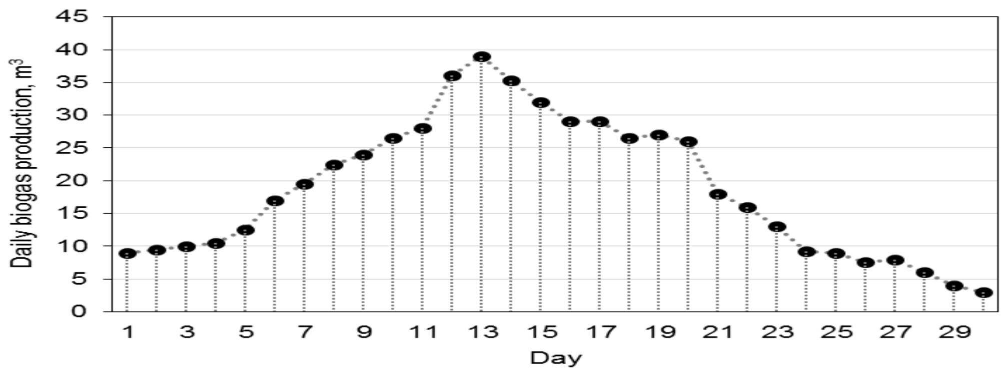


Figure 11. Cumulative production of biogas

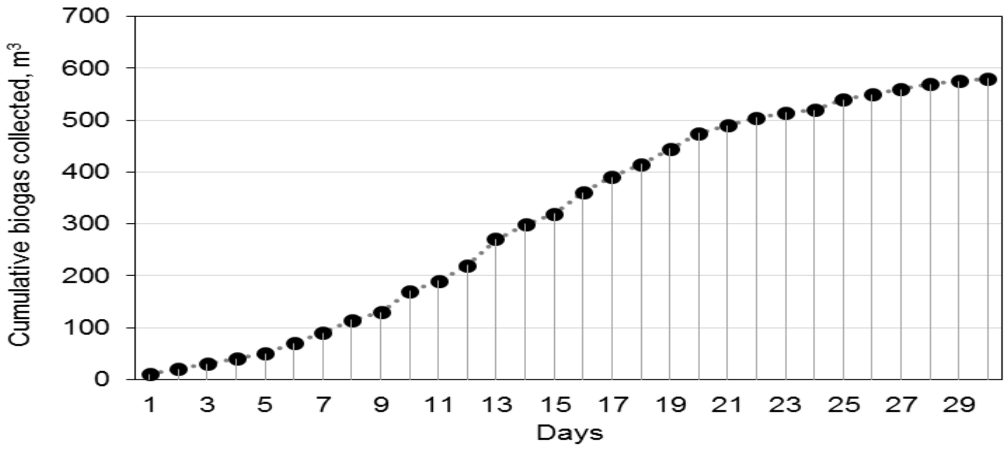
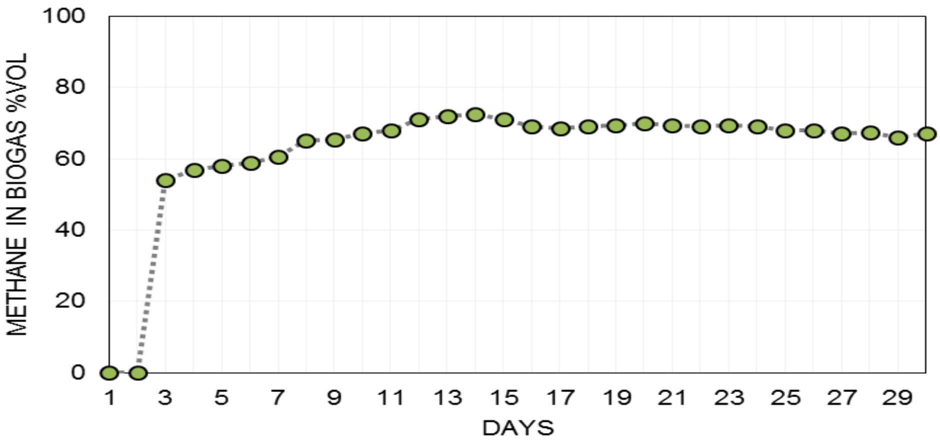


Figure 12. Methane content in produced biogas

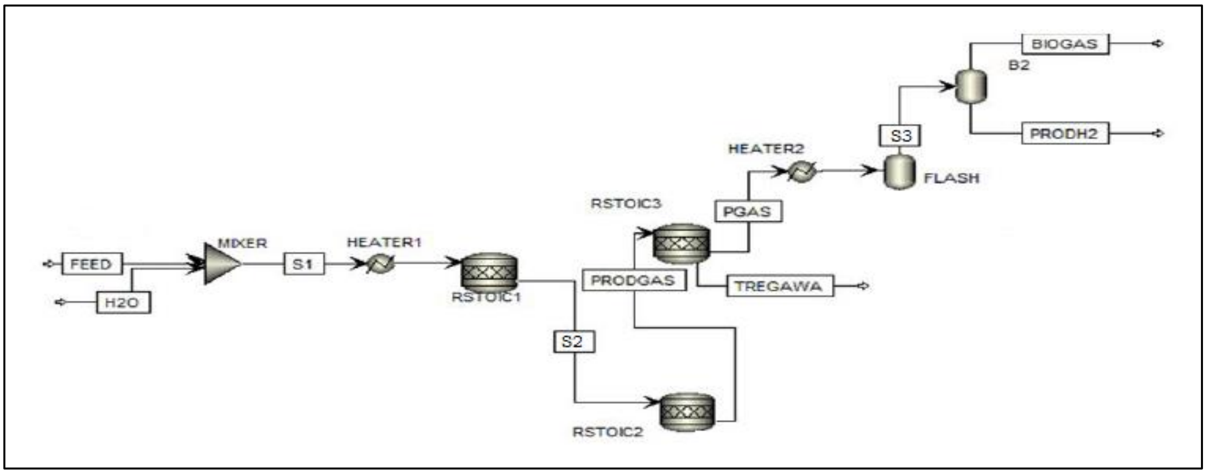


The fermentation volume of 3 $m^3$was adequate for one cow that produces 19 kg of manure daily. The number of cows on the farm determines the amount of fermentation material to be produced. Due to the lack of a gas chromatography device, the proportions of the biogas components were not determined. The flammability test was used as an indication of the proportion of carbon dioxide in the equivalent sample or equivalent to the proportion of methane gas. Through this test, a high percentage of methane gas was found after about 480 h.

4.1 Simulation Investigation

A simulation model was prepared based on hydrolysis, acid, and methane generation from animal residues (cows and chickens) (Aspen Technology, 2010). This process breaks down organic matter into more explicit materials and produces methane and carbon dioxide. Figure 8 illustrates a simulation model developed using Aspen Plus by which the remains of chicken and cow rich in carbohydrates were selected and simulated. A two-liquid model was chosen in this study, where the liquid and gas stages were included (Iqbal *et al.* 2014).

Figure 13. Aspen Plus to a simulation of the process of aerobic decomposition



Standard conditions were used for the participating units as the temperature ranged from 35 to 52 degrees Celsius and pressure from 3 to 8 bars. S1 was for hydrolysis, S2 was for adding acids, and S3 was for methane and hydrogen production. The mixture mold was used to exploit the precipitate, while the heaters were used to increase the mixture's temperature. Some factors affect biofuel production, such as daily feeding, hydrogen, pressure, and temperature (Giuliano *et al.* 2013). The simulation was done by changing the feeding amount to 20%, 40%, and 60%. Simulations were also done with different operating pressures of up to 6 bar and different flow temperatures (15, 35, and 50˚C). 1.5 kg of cow manure and chicken droppings was added at a time into the digester.

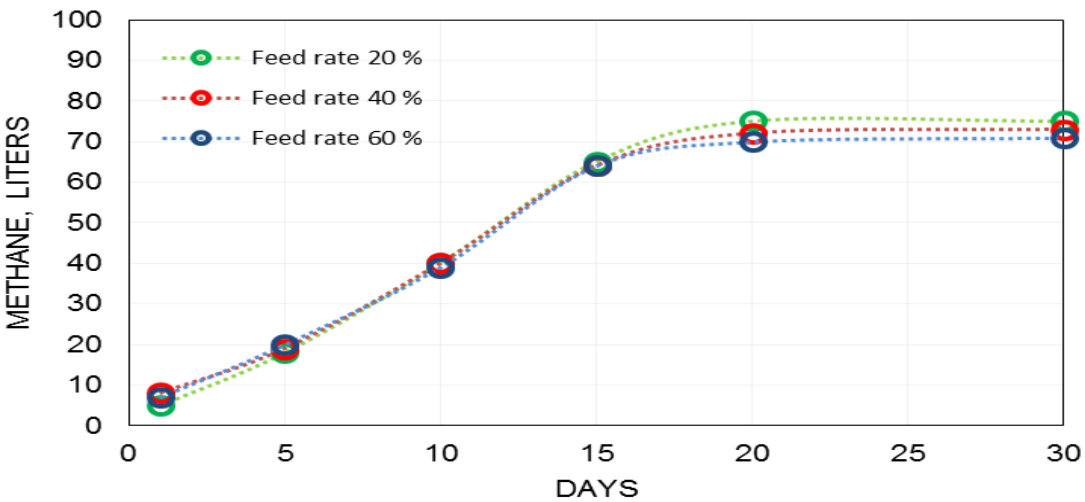
5. Results and Discussion

The anaerobic digestion simulation model by Aspen Plus needs feeding values to run the simulation correctly. Anaerobic digestion is carried out by microorganisms; this makes simulation difficult in Aspen, and the program is limited to kinetics and interactions only.

5.1. Effect of Feeding Ratios

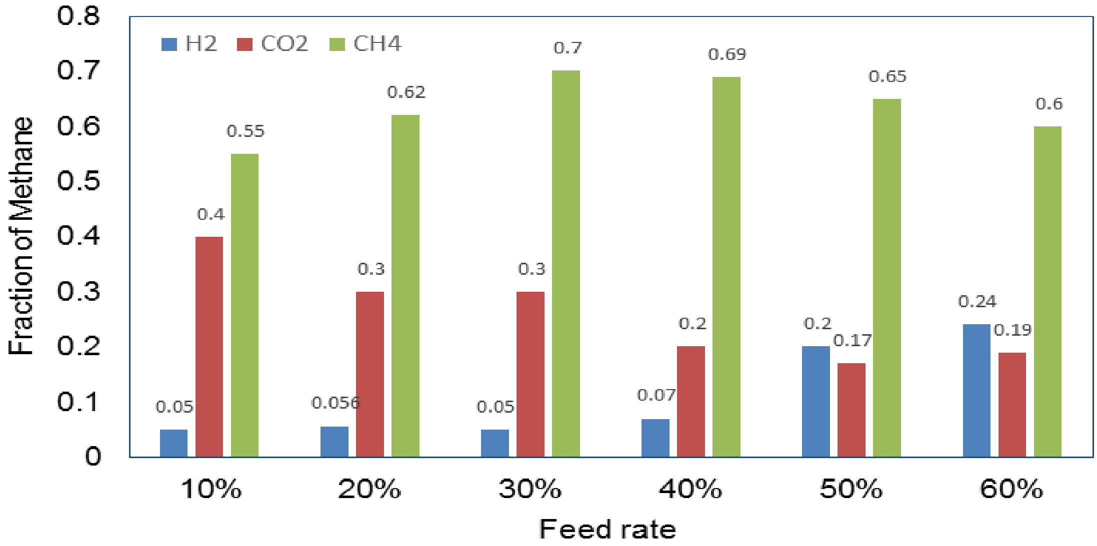
The rate of biogas production depends on the input feed ratio. Figure (9) showed the results of simulating the feed rate of different organic materials from 1.5 kg per day at a concentration of 20%, 40%, and 60% of the inputs.

Figure 14. Amount of gas produced at different feed rates



The highest value of methane production was 75 liters at the feeding rate of 20%. For the rest of the ratios for this flow rate, the methane rate decreased because the extra organic matter would act as an inhibitor in a particular case. The decrease was due to the precipitated substances that did not contribute to methane production, as studied experimentally by Luo and Irini (2012). The optimum feeding rate value varies for other biomass feeding types as each organic source of biofuel production varies in terms of results and outputs.

Figure 15. Composition of methane, carbon dioxide, and hydrogen with different feed ratios

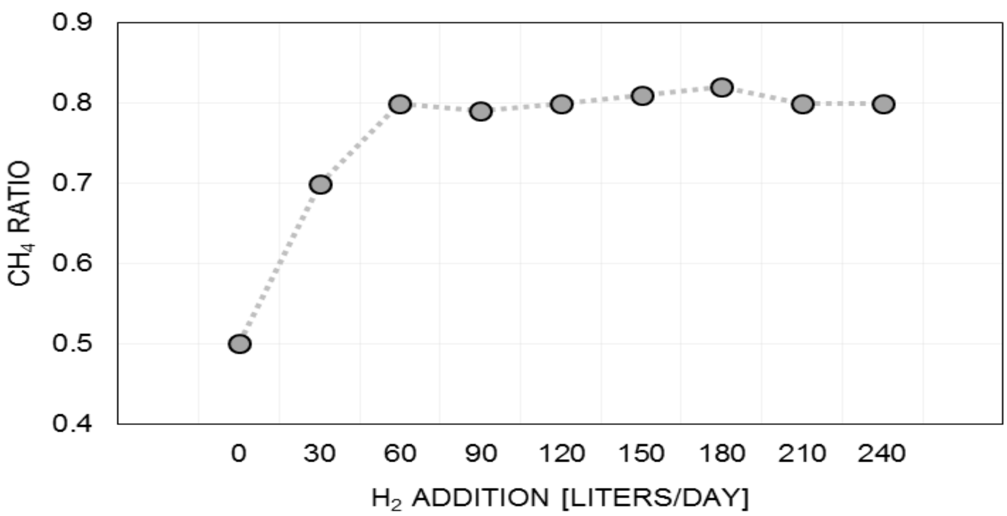


The biogas produced consist of methane, carbon dioxide, and hydrogen at specific feeding rates. The number of methane increases as the feeding rate increased from 15% to 30% at a daily concentration. This ratio stimulated the bacteria to produce more methane. A shown in Figure 15, the methane gas composition was 0.70 at the average rate of 30% to 40%; then, the production rate decreased as the feeding rate increases.

5.1.2 Effect of Adding Hydrogen

Adding hydrogen gas to the aerobic digestion process can increase methane production (Zupančič and Grilc, 2012; Aspen Technology, Inc. 2010). However, the added hydrogen ratio must be equal to the amount of hydrogen produced from the acid fermentation process. The simulation was done using a hydrogen gas stream, where the microorganisms are expected to consume the hydrogen gas to produce methane (Greater London Authority 2018). When adding hydrogen gas, the formation of methane gas began with the increase in hydrogen gas content until the maximum value is reached (see Figure 11). The organic matter inhibition occurs due to the increase in hydrogen gas flow into the system and the increase in acidity. The maximum value of methane gas obtained was 0.83 when 170 liters/day of hydrogen gas was introduced.

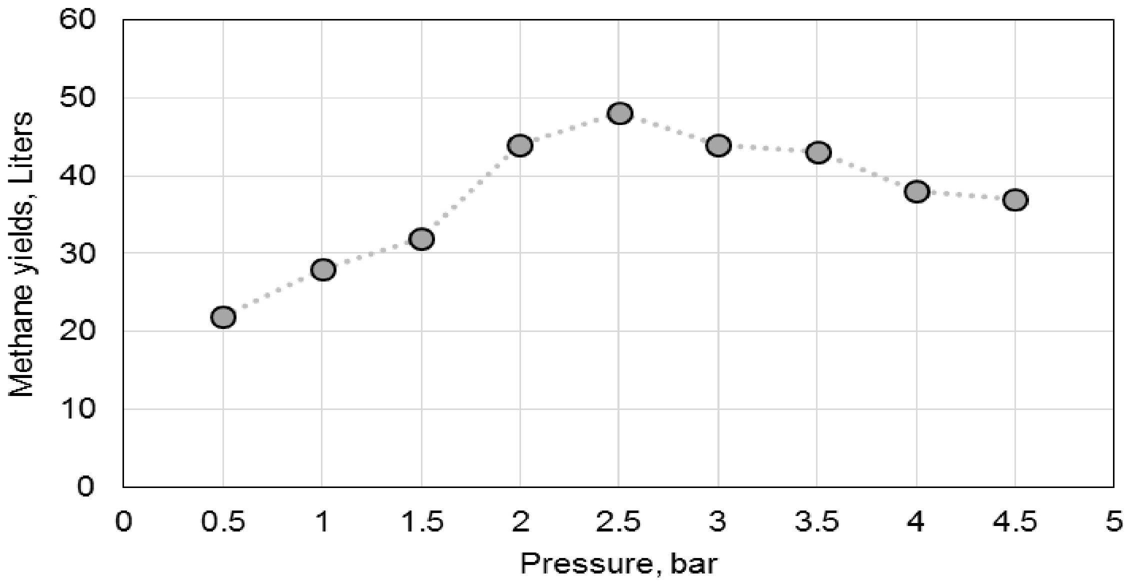
Figure 16. Effect of hydrogen addition to methane production



5.1.3 Effect of Operating Pressure

Pressure changes were made from 0.5 to 4.5 bar in the Aspen Plus simulation model. Figure (17) illustrates the different pressure changes that affected the level of methane production. When the operating pressure was increased from 0.5 bar to 2.5 bar, methane production increased from 22 liters to 48 liters, respectively. As the optimum pressure is 3 bar, values greater than 3 bar of operating pressure decrease methane production because the degradation process becomes unstable at high pressures (Elmnifi *et al.* 2018).

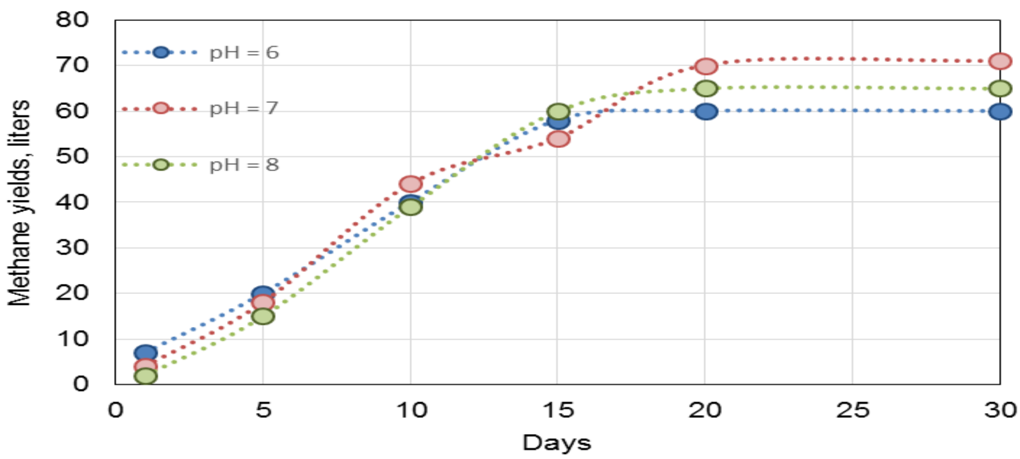
Figure 17. Effect of operating pressure on methane production



5.1.4 Effect PH

The anaerobic fermentation process is sensitive to changes in acidity, and this is due to the type of organic matter used. Simulations were performed for the pH values of 6, 7, and 8 as in Figure 18. The largest amount of gas produced was at pH = 7 (about 70), followed by pH = 8 (about 65 liters) and pH = 6 (about 60 liters). From the results, the pH was observed to hinder the formation of methane.

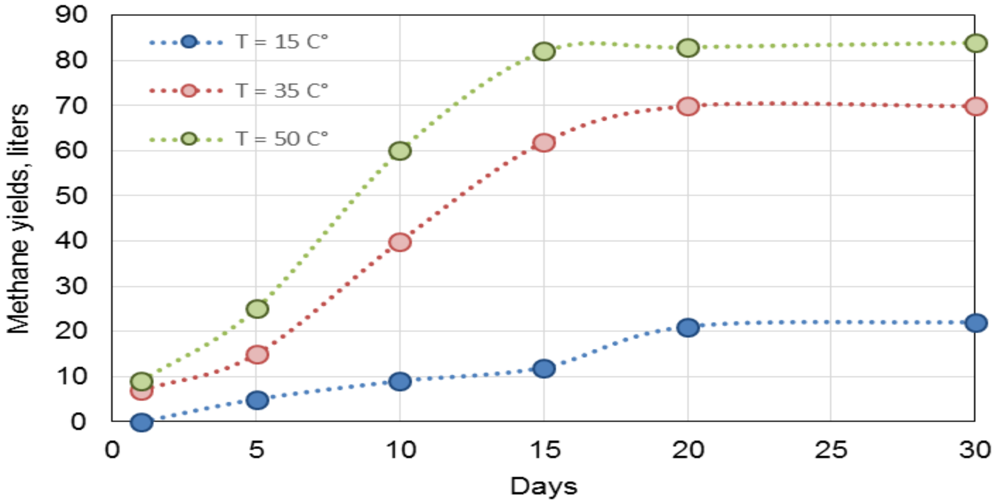
Figure 18. Amount of methane produced at different pH values



5.1.5 Effect Temperature

The temperature affects the methane production process as simulated in the program using three temperature values of 15, 35, and 50°C. It was noticed in Figure 19 that an enormous amount of methane gas was produced at a temperature of 50°C (about 86 liters) while the amount of gas produced at 15 and 35°C was about 23 and 70 liters, respectively. A higher flow temperature increases the amount of gas produced and reduces the mixture's fermentation time.

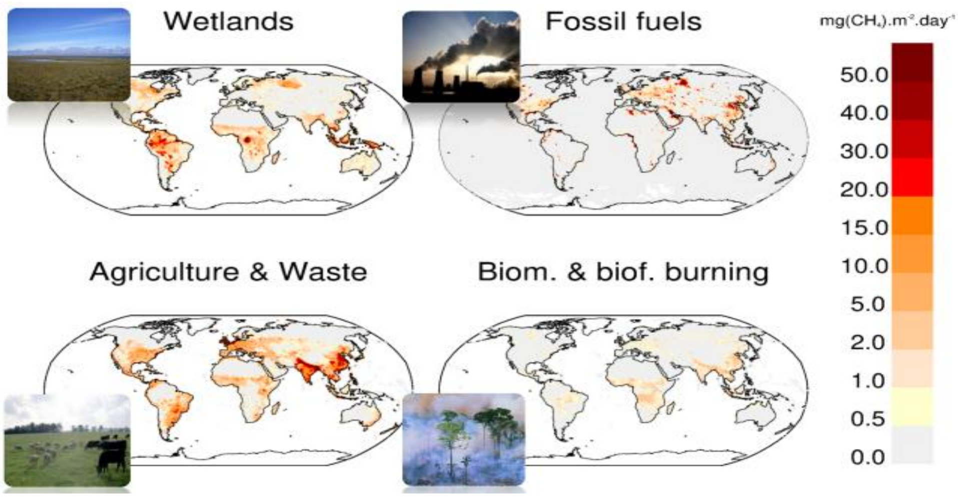
Figure 19. Effects of temperature on methane production



6. Environmental Methane Effect

After carbon dioxide (CO_2), methane (CH_4) is the second most crucial well-mixed greenhouse gas contributing to human-made climate change. CH_4 has the potential for global warming, 86 and 28 times greater than carbon dioxide for the time horizon of 20 and 100 years, respectively. The atmosphere's methane level is two and a half times higher than pre-industrial levels and is responsible for 23% of global warming from all well-mixed greenhouse gases. Methane remains in the atmosphere for nine years, unlike hundreds to thousands of years of carbon dioxide. About 60% of all methane emissions come from human sources, with a total of 366 (399-349) Terra Gram (Tg) of CH_4 for the decade 2008-2017. The most important sources are emissions from agriculture and waste, as intestinal fermentation and manure are the essential sources. Fossil fuel extraction and processing is the second most important source, with slightly faster growth than cultivation compared to the previous decade, as shown in Figure 20.

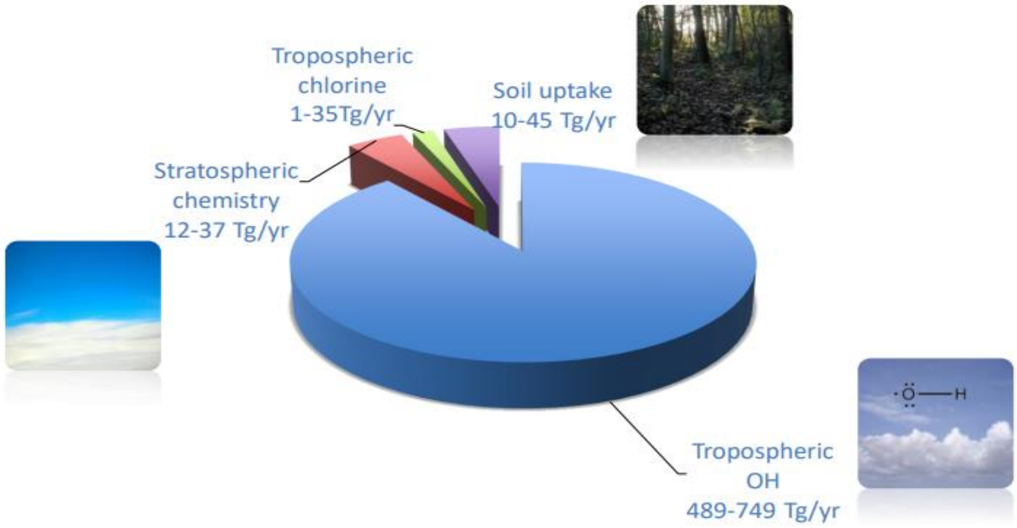
Figure 20. Natural sources of methane gas from 2008-2017



Source: Saunois M., *et al. 2020*

Natural emissions of methane are 371 (245-488) Tg of methane for the 2008-2017 decade and are dominated by emissions from wetlands. Freshwater bodies such as lakes and rivers are the second most important source, followed by geological sources like leaks and volcanic land and marine volumes. Other smaller sources include ruminant wildlife, termites, hydrates, and permafrost. Several chemical and biological processes in the atmosphere and soil consume methane and are thus methane basins. The primary basin is oxidation by hydroxyl radicals (OH), most of which are in the troposphere, accounting for about 90% of the global methane sink. Other basins include methanogens in aerobic soils, interactions with chlorine roots and atomic oxygen roots in the stratosphere, and interactions with chlorine roots from sea salt in the marine boundary layer, as shown in Figure (21).

Figure 21. The proportion of methane consumed in the soil and atmosphere



Source: Saunois *et al.* (2020)

Conclusions

In this study, experimental and simulation studies verified the anaerobic digestion of animal waste for biofuel production. The results indicated that biofuels could be produced with a cumulative rate of 564.3 m^3 and a daily production rate of 18.81 m^3 from every animal waste. A three-stage simulation model was used to simulate the pyrolysis performance using Aspen Plus. The Aspen Plus simulation results on the effects of temperature, hydrogen flow, the acid content of raw materials, and operating pressure on biogas production were analyzed and discussed. The optimum reactor temperature varies with the rate of hydrogen flow to maximize biogas productivity because this rate controls the feeding of microorganisms. The quantitative content of raw materials can significantly affect the amount of gas and the duration of fermentation. The simulation results showed that biogas production was affected by the rate of hydrogen flux, operating pressure, temperature, and pH of the mixture. The optimum production level for biomethane was 75 liters at the feed flow rate of 20%, a hydrogen flow rate of 180 liters/day, the pressure of 2.5 bar, pH value of 7, and the operating temperature value of 50°C. These results suggest that biogas production through anaerobic digestion could be an alternative renewable source of energy.

Acknowledgments

The authors would like to gratefully thank the Faculties of Technologies and Engineering Sciences at Bright Star University in Libya for their support.

References

[1] Chakraborty, M., Sharma, C., Paney, J., and Gupta, P.K. 2013. Assessment of energy generation potentials of MSW in Delhi under different technological option. *Energy Conversion and Management,* 75: 249–255. DOI: 10.1016/J.ENCONMAN.2013.06.027

[2] Chen, L., and Neibling, H. 2014. *Anaerobic Digestion Basics* (Moscow: University of Idaho Extension).

[3] Cho, Y., and Young, G. 2018. *Modeling the Performance of Fixed-Film Anaerobic Reactors*, *792:* 1949.

[4] Clark, B. and Rogoff, M. 2010. Economic feasibility of a plasma arc gasification plant, city of Marion, Iowa. Paper presented at the 18th Annual North American Waste-to-Energy Conference, May 11-13th, In Orlando, Florida, USA.

[5] Deublein, D., and Steinhauser, A. 2011. *Biogas from Waste and Renewable Resources: An introduction*, 2nd Revised and Expanded Edition, Willey Online Library.

[6] el, C., Custudio, O., Tongco, E., and Tiangco, C.C. 2006. Promotion of Renewable Energy, Energy Efficiency and Green House Gas Abatement (PREGA) Philippines Waste to energy Project. Tech. rep., Pineapple Processing Waste Biomethanation and Treatment Plant A Prefeasibility study report, prepared by PREGA National Technical Experts from CPI Energy Philippines.

[7] Elmnifi, M., Alshilmany, M., and Abdraba, M. 2018. Potential of Municipal Solid Waste In Libya For Energy Utilization. *Open Journal of Mechanical Engineering*, *2*(2): 01-05. DOI: 10.26480/ojme.02.2018.01.05

[8] Elmnifi, M., Amhamed, M., Abdelwanis, N., and Imrayed, O. 2017. Waste-to-energy potential in tripoli city-libya. *Environment & Ecosystem Science*, *2*(1): 01-03. DOI: https://doi.org/10.26480/ees.01.2018.01.03

[9] Gebril, A.O., Omran, A., Pakir, A.K., and Aziz, H.A. 2010. Municipal solid waste management in Benghazi (LIBYA): Current practices and challenges. *Environmental Engineering and Management Journal*, *9*(9): 1289-1296. DOI: 10.30638/eemj.2010.167

[10] Ghorbanian, M., Lupitskyy, R.M., Satyavolu, J.V., and Eric Berson, R. 2014. Impact of supplemental hydrogen on biogas enhancement and substrate removal efficiency in a two-stage expanded granular sludge bed reactor. *Environmental Engineering Sciences*, 31(5): 253–60. DOI:https://doi.org/10.1089/ees.2013.0496

[11] Giuliano, A., *et al.* 2013. Co-digestion of livestock effluents, energy crops and agro-waste: feeding and process optimization in mesophilic and thermophilic conditions. *Bioresource Technology*, 128: 612-618. DOI:https://doi.org/10.1016/j.biortech.2012.11.002

[12] Gotmare, M., Dhoble, R., and Pittule, A. 2011. Biomethanation of dairy wastewater through UASB at mesophilic temperature range. *International Journal of Engineering and Advanced Technology*, 8 (1): 001–009. DOI: 10.48175/IJARSCT-2868

[13] Hamilton, D.W. 2009. Anaerobic Digestion of Animal Manures: Understanding the Basic Processes, Oklahoma.

[14] Iqbal, S.A., Rahaman, S., Rahman, M., and Yousuf, A. 2014. Anaerobic digestion of kitchen waste to produce biogas. *Proccess Engineering*, 90: 657-62. DOI: 10.1016/J.PROENG.2014.11.787

[15] Lim, S.J. 2011. Comparisons between the UASB and the EGSB reactor, *Iowa State University Publications*, 17 (1969): 1–17.

[16] Luo, G., and Irini, A. 2012. Integrated biogas upgrading and hydrogen utilization in an anaerobic reactor containing enriched hydrogenotrophic methanogenic culture. *Biotechnol Bioeng*, 109(11): 2729-36. DOI:10.1002/bit.24557

[17] Lusk, P. 1998. Methane Recovery from Animal Manures the Current Opportunities Casebook, National Renewable Energy Laboratory (NREL), *Resource Development Associates Washington*, DC, September, p. 1-150.

[18] Malakahmad, A., Md Zain, S., and Basri, N.E.A. 2012. Biomethanation of kitchen waste and sewage sludge in anaerobic baffled reactor. Paper presented at the 2012 IEEE Symposium on Humanities, Science and Engineering Research, June 24-27, in Kuala Lumpur, Malaysia.

[19] Meegoda, J.N., Brain, L., Patel, K., and Wang, L.B. 2018. A review of the processes, parameters, and optimization of anaerobic digestion. *International Environmetal Research of Public Health*, 15(10): 2224. DOI:10.3390/ijerph15102224

[20] Moriarty, K. 2013. *Feasibility Study of Anaerobic Digestion of Food Waste in St. Bernard, Louisiana*, National Renewable Energy Laboratory (NREL), Resource Development Associates Washington, DC, January.

[21] Omran, A., and Gebril, A.O. 2018. Municipal Solid Waste Management Practices in the Central Part of Libya. Chapter in a Book, The Impact of Climate Change on Our Life. DOI: 10.1007/978-981-10-7748-7_8

[22] Omran, A., Alsadey, S., and Gavrilescu, M. 2011. Municipal solid waste management in Bani Walid City, Libya: Practices and challenges. *Journal of Environmental Management and Tourism, II* (2): 228-237

[23] Omran, A., Altawati, M., and Davis, G. 2018. Identifying municipal solid waste management opportunities in Al-Bayda City, Libya, *Environment Development and Sustainability,* 20(4). DOI: 10.1007/s10668-017-9955-3

[24] Rouse, S. 2013. Precise Biogas Flow Measurement: Overcoming the Challenges of Changing Gas Composition, Sierra Instruments, Monterey.

[25] Saunois M., *et al.* 2020. The Global Methane Budget 2000–2017. *Earth System Sciences Data*, 12: 1561–1623. DOI: https://doi.org/10.5194/essd-12-1561-2020

[26] Zupančič, G., and Grilc; V. 2012. Anaerobic Treatment and Biogas Production from Organic Waste, in Management of Organic Waste, S. Kumar, Ed. Slovenia: In Tech, p. 198.

[27] Aspen Technology, Inc. 2010. ASPEN Plus—Getting Started Modeling Processes with Solids, V10.2, Aspen Technology, Inc.: Bedford, MA, USA.

[28] Greater London Authority 2018. Cost of Incineration and Non- Incineration Energy-from-waste-technologies, Tech. rep. Available at: http://legacy.london.gov.uk/mayor/environment/waste/docs/efwtechnologiesreport.pdf

[29] Metro Waste Authority. Strategic Business Plan, 2012–2013. Metro Waste Authority, Tech. rep. Available at: https://www.mwatoday.com/webres/File/2021-2022%20Strategic%20Business%20Plan.pdf

ASERS

ASERS
Publishing

Web: www.aserspublishing.eu
URL: http://www.journals.aserspublishing.eu/jemt
E-mail: jemt@aserspublishing.eu
ISSN 2068 – 7729
Journal DOI: https://doi.org/10.14505/jemt
Journal's Issue DOI: https://doi.org/10.14505/jemt.v14.1(65).00