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# Biogas Extraction Using Organic Waste (Domestic and Animal) as an Alternative Natural Resource to Traditional Energies

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**Abstract:** This study was conducted in the city of Tobruk, located in north eastern Libya, during the summer season. It lasted for a duration of 88 days. Anaerobic digestion processes are among the most widely used techniques for treating organic waste for the production of biogas (Methane gas) as a source of clean energy. Therefore, household waste (food remnants), cow manure and a homogeneous mixture of them in a 1:1 ratio were used as a source for methane gas production. The study also investigated the impact of various operational factors, including air temperature, humidity, dry temperature, and pH levels on biogas production. The results revealed that the biogas production (methane gas) from household waste was satisfactory at the beginning of the experiment. However, production decreased due to the accumulation of volatile acids up to 32 days. The production rate was 0.27 liters per kilogram of household waste, with an average ambient temperature of 30.7°C, dry temperature of 36.2°C, humidity of 36.8%, and a pH of 3.7. In contrast, the cow dung experiment lasted 88 days, with production reaching 0.56 liters per kilogram, with an average ambient temperature of 30.4°C, dry temperature of 36.5°C, humidity of 37.5%, and a pH of 6.6. Whereas the mixture sample experiment lasted 22 days, which had the highest production at 0.79 liters per kilogram, with an average ambient temperature of 31.4°C, dry temperature of 36.3°C, humidity of 36.3%, and a pH of 5.4, indicating the homogeneity of materials within the digestion unit. The study concluded that anaerobic digestion has the potential to be a sustainable technology for recycling food waste and cow manure and echo-friendly and clean energy through methane producing.

**Key words:** Biogas % Methane % Renewable energy % Organic waste % Cow dung

## INTRODUCTION

Most countries of the world depend on energy materials that can be converted into heat, electricity and fuel. Non-renewable resources are currently the most widely used source of energy, and the use of fossil fuels such as coal and petroleum-based products has led to severe negative impacts on the environment and human health [1, 2].

The increased demand for non-renewable energies has led to an increase in greenhouse gas emissions and climate change in the world [3]. This consumption of non-renewable energy may lead to the exhaustion of its sources, because they are limited and will eventually run out. consequently,it may lead to major economic and social unrest, especially in developing countries that rely heavily on non-renewable energy for their economies [4].

To address the challenge of non-renewable energy depletion problem, many countries are investing in renewable energy sources such as biomass energy, solar energy, wind energy and hydropower. These renewable energy sources have the ability to provide a sustainable source of energy that is inexhaustible and does not contribute to climate change or depletion of limited resources [5].

Recent studies have shown widespread interest in bioenergy as it is an important energy source globally as a greenhouse gas-neutral alternative to fossil fuels [6]. Traditional biomass products, which currently represent about 10% of global energy consumption, include

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agricultural waste, human waste from food scraps, sewage, animal manure, forest products, and collected wood as a major source of living energy. The studies of [7,8] have shown the feasibility of using the anaerobic digestion process to produce methane from food waste and livestock manure. These studies evaluated the effects of various factors, such as hydraulic retention time, organic loading rate, and pH, on methane production. The study concluded that anaerobic digestion has the potential to be a sustainable technology for treating food waste and producing methane.

Therefore, this study aimed to throw the light on biomass through the impact of human consumption patterns on the increase in household and animal waste in the study area in order to to produce methane gas through anaerobic fermentation of organic, household and animal waste, and to use this gas on a large scale as a primary source of energy. Another target of the study is to use clean renewable energy in the field of electricity generation, heating, etc. as well as encouraging the process of sustainable development, and proper disposal of organic waste in a safe manner and benefiting from it economically.

## MATERIALS AND METHODS

**Study Area:** The study was conducted in the city of Tobruk, which is geographically located in northeastern Libya, bordered by the Mediterranean Sea to the north. As for astronomically, the city of Tobruk is located at the intersection of longitude 27°, 58', 24 east, and latitude 4°, 5', 32 north (Figure 1). According to the 2023 statistics, the population of the city of Tobruk is about 138,363 people. Its climate is also characterized by a Mediterranean climate that is hot and dry in summer and moderate rain in winter, in which the average temperature reaches 31 degrees during the summer.

**Collection of Organic Waste (Domestic and Animal):** The food waste used in the experiment is heterogeneous in nature as it consists of cooked and uncooked household food waste which was collected from the city's garbage dump. Also, cow manure was completely collected from one of the cow and livestock farms in the study area. The organic waste was separated from other solid waste, as well as the process of breaking up and cutting the organic waste from cow dung before entering it into the digester units in small sizes in order to help facilitating the process of microbial decomposition inside the digester. The packing process was carried out as follows:

1. The first treatment (A): food leftovers from household waste, the second treatment: cow manure (B), the third treatment (C): a mixture of household waste and cow manure in a ratio of 1:1 [9].

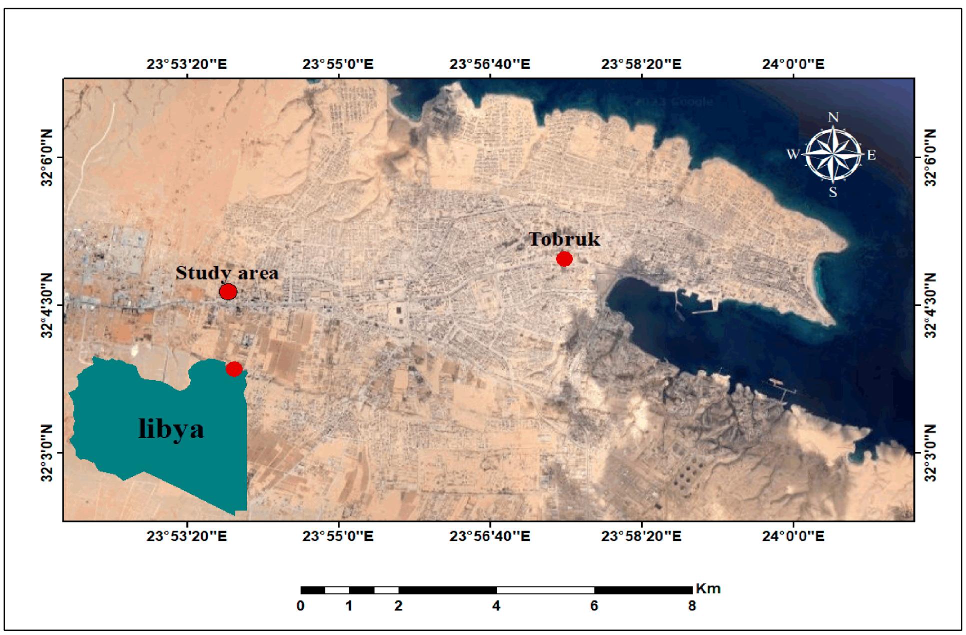


Fig. 1: Study site - Tobruk city - eastern Libya

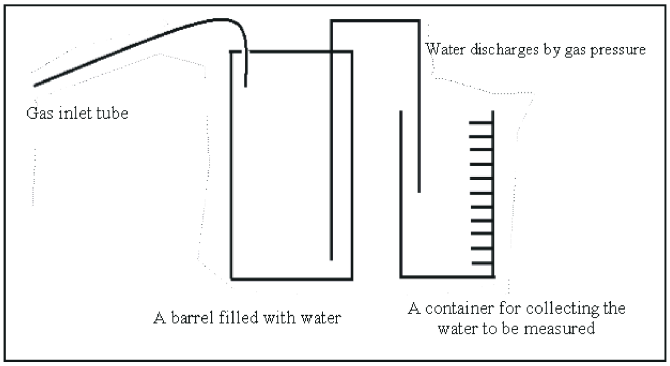


Fig. 2: The process of measuring the gas produced by the water displacement method is as stated by [11].

2. The previously mentioned waste was placed in nine (9) sealed iron drums used as anaerobic digesters, with a capacity of (200 liters), divided into (3) treatments and (3) replicates for each type of waste, as follows:

- Adding 40 kg of leftover food waste to each unit of the first and repeated treatments, and is symbolized by the symbol (A).
- Adding 40 kg of cow manure waste to each unit of the second treatment and the duplicates, and it is symbolized by the symbol (B).
- Adding 40 kg of a mixture of food scraps and cow manure to each unit of the third treatment and the replicates, and symbolize it with the symbol (C).
- Water was added to all treatments according to [10] in a ratio of 1:2.5.
- The air temperatures were measured using a thermometer, as well as the internal temperatures of the condenser (wet and dry) using an electronic thermometer, and the pH was measured using a pH meter of the solution every day at mid -day allthe experiment duration.
- The amount of gas produced was measured in liters by displacement with water (Figure 2), as stated by [11].
- The organic matter was stirred inside the barrels at intermittent intervals.

**Statistical Analysis:** A completely randomized CRD design was chosen in three replications. Statistical analysis was performed for all studied characters in the experiment after tabulating them statistically using the Gnestat program. Treatment means were compared using the Least Significant Difference (L.S.D.) test at a 5% significance level [12].

## RESULTS AND DISCUSSION

The retention time of household waste (food leftovers treated (A) was monitored for 32 days, and the gas produced during this period was discharged twice, and the total gas production amount was (342) liters/40 kg of biomass. The retention time of the cow manure treatment (B) was also monitored for 88 days, and the produced gas was discharged ten times during this period, and its quantity was (1975) liters/40 kg of biomass. As for treatment (C), which is a mixture of food scraps and cow manure, its retention time was monitored for 22 days, and the gas was discharged four times, and the gas quantity during this period was (697) liters/40 kg of biomass, as shown in Figure 3.

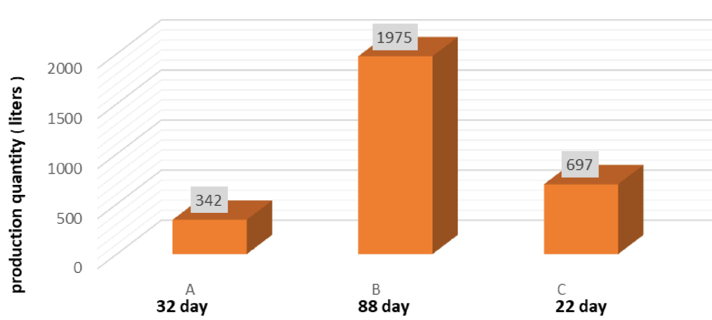


Fig. 3: Quantity of biogas production in liters during the period of each treatment in the study (A, B, C).

**Anaerobic Digestion Activity Within the Biomass of the Treatments in the Study:**

**Treatment (A) Household Waste (Food Leftovers):** The data presented in Figure 4 show the wet and dry temperatures, air temperature, and pH of the study samples of treated food residues (A) during a period of 32 days of substrate retention time inside the digester. The goal of this experiment is to understand the possible relationship between these variables and their effects on the production of Biogas. The results of dry and wet temperatures and air temperature depend on a daily basis, and these data are linked to changes in the environment and climatic conditions prevailing in the study area during the experiment period. The measurements showed the similarity of wet temperatures, which had a maximum value of 39.3, a minimum value of 34.1, and an average value of (36.8), as well as dry temperatures, a maximum value of 39.4, a minimum value of 33.7, and an average value of (36.2). The maximum value of air temperatures was 34.0, and a minimum value of 28.5, and an average value of (30.7). Through these results, it is clear that the temperatures are close together, whether wet or dry, or air temperatures. This indicates environmental balance and harmony within the anaerobic digestion unit, which contributed to the production of methane gas. The closeness of the temperatures is due to the availability of optimal conditions for methanogenic bacteria and the balance of the sample organic components. (carbohydrates, proteins, fats).

The maximum pH was 3.9, the lowest value was 3.5, and the average value was (3.7), since anaerobic digestion is a biological process in which microorganisms break down organic materials in the absence of oxygen. During this process, complex organic compounds are converted into simpler molecules, including various acids and gases. The main reason for the decrease in pH levels in the anaerobic digestion system with food waste may be the accumulation of volatile fatty acids (VFAs), which are a group of organic acids, the accumulation of which leads to a decrease in the pH inside the digester. Consequently, this leads to an increase in ammonia inside the digester, which causes inhibition in the biogas production process [13].

**Treatment (B) Cow Manure:** The data presented in Figure 5 show the wet and dry temperatures, air temperature, and pH of the treated study samples (B) during the 88-day period of substrate retention time inside the digester. The measurements showed the closeness of the wet temperatures, which had a maximum value of 41.4, a minimum value of 33.1, and an average value of (37.5). Also, dry temperatures had a maximum value of 41.2, a minimum value of 32.0, and an average value of (36.5). The maximum value of air temperatures was 35.0, the minimum value of 28.0, and their average value of (30.4). Although the results show similar wet and dry temperatures and air temperatures, it is important to compare them with results from previous studies to understand the broader context and potential impact of these results.

It has been discovered that this closeness plays a key role in forming a favorable environment for the activity of bacteria responsible for digesting organic matter and producing biogas. In addition, air temperatures play an important vital role, as their proximity can contribute to achieving a balance in biological processes within the digester, leading to improved biogas production.

Different biomasses react uniquely to temperature changes during anaerobic digestion processes, and this may cause changes in the structure and function of the microbial community. Understanding these changes in microbial communities is of particular interest, as they can influence methane production rates when temperatures change [14].

The results of the study also showed that the maximum value of pH was 7.1, while the lowest value was 5.5, and the average values were (6.6). These values reflect average levels of acidity in the anaerobic digestion unit during biogas production from cow dung residue. These are consistent with a study by [15] where the effect of hydrogen values (pH) on biogas production was analyzed. The study found that pH can have a significant impact on the composition of microbial communities within the anaerobic digestion unit. Therefore, these values can play a crucial role in bacterial diversity and activity, thus stimulating biogas production. This also agrees with another study conducted by [16] that the pH balance can affect the efficiency of the biogas production process. The results of the study indicate that large fluctuations in pH may stimulate some bacteria and inhibit others, which could affect the composition of microbes and thus affect biogas production.

Therefore, it can be said that pH plays a crucial role in biogas production under anaerobic digestion conditions. Studies confirm that pH balance may be useful for improving the efficiency of biogas production. Based on these results, wet and dry temperature and air temperature are considered stimulating factors for biogas production [17].

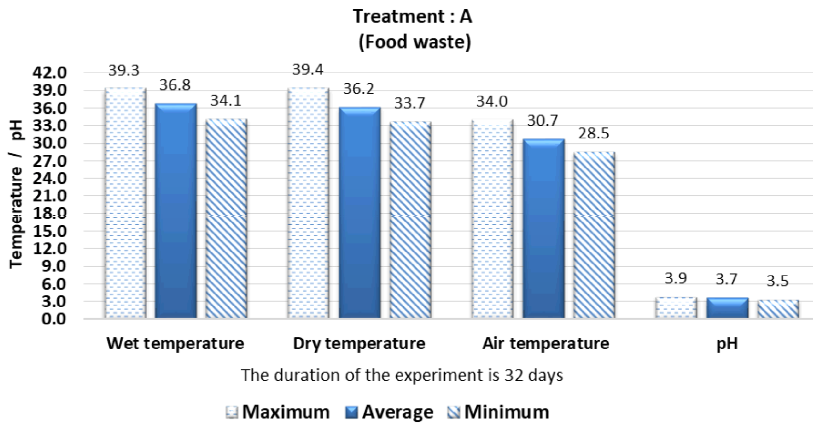


Fig. 4: Treatment (A) wet and dry temperatures, air temperature and pH during a period of 32 days.

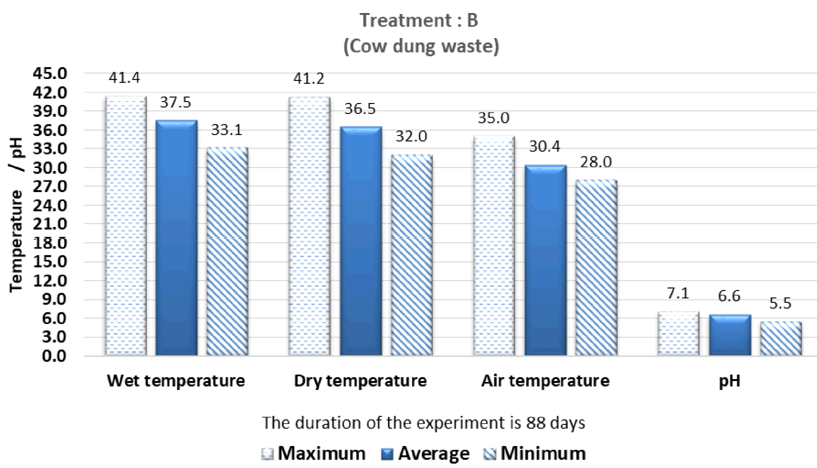


Fig. 5: Treatment (B) wet and dry temperatures, air temperature and pH during a period of 88 days.

**Treatment (C) Mixture of Cow Dung and Food Scraps:** The data presented in Figure 6 show the wet and dry temperatures, air temperature, and pH of the study samples over a period of 22 days of substrate retention time within the digester. The wet temperature measurements showed a maximum value of 39.4, a minimum value of 34.2, and an average value of (36.3). Also, dry temperatures showed a maximum value of 39.8, a minimum value of 34.6, and an average value of (36.3). The maximum value of air temperatures was 34.0, and a minimum value of 30.0, and an average value of (31.4). These results indicate that wet and dry temperatures and air temperature are similar, indicating that the ambient conditions within the digester unit are consistent.

This is consistent with a study conducted by [18] indicating the importance of temperature stability in improving the anaerobic digestion process. Medium and stable temperatures can stimulate the growth of methanogenic bacteria and enhance the efficiency of biogas production. It is also consistent with another study conducted by [19] that the optimal conditions for the anaerobic digestion process include medium temperatures and balanced humidity. This study found that these conditions can positively affect the activity of methanogenic bacteria and thus enhance biogas production.

The obtained results also showed that the maximum value of pH was 5.7, while the lowest value was 5.1, and the average values were (5.4). From the aforementioned results and previous studies, it can be concluded that the convergence of wet and dry temperatures and air temperature reflects the existence of optimal conditions within the anaerobic digestion unit, which enhances the improvement of the biogas production process.

**Biogas (Methane) Production in the Study:**

**Treatment (A) Production of Biogas from Household Waste (Food Leftovers):** Figure 7 and Table 1 show the cumulative production of biogas during the 32-day

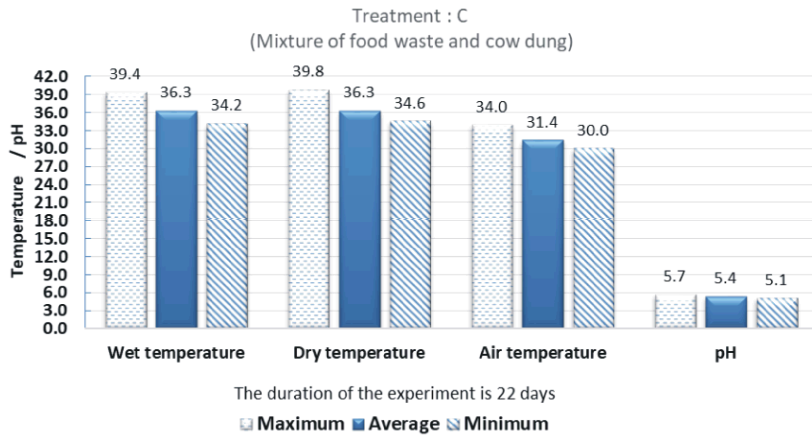


Fig. 6: Treatment (C) wet and dry temperatures, air temperature and pH during a period of 22 days.

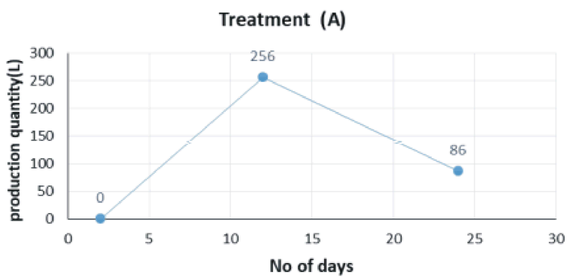


Fig. 7: Quantity of methane gas production (litres) / 40 kg live mass.

digestion period, which amounted to 342 litres/40 kg (treatment A). We find that the values of the volume of biogas produced by the process of anaerobic digestion of organic household waste gradually increased from zero to reach its peak on the twelfth day, when the volume of biogas produced reached 256 liters, then it decreased again, reaching 86 liters on the twenty-fourth day, that is, at a rate 10.687 liters/40 kg/day, equivalent to 0.27 liters/ One kilogram/day as shown in Table 1.

In the initial stages of anaerobic digestion inside the digester, large amounts of gas are formed as a result of the rapid decomposition of organic materials. This could explain the rapid increase in gas production until the 12th day. The decrease in biogas over time is due to the decomposition and consumption of organic materials during the first stage of production as well as the accumulation of inhibitory substances. During the anaerobic digestion process, inhibitory substances such as long-chain fatty acids may form. These substances may reduce the activity of bacteria and thus reduce gas production. In addition, there may be a change in the balance of bacteria involved in anaerobic digestion, leading to a decrease in gas production.

Digestion conditions such as temperatures and pH can affect gas production as shown in this study in Table 1. If these conditions are not optimal, gas production may be reduced [20].

**Treatment (B) Production of Biogas from Cow Manure:** Figure 8 and Table 1 show the cumulative production of biogas during the digestion period of 88 days, which amounted to 1975 litres/40 kg in treatment (B). We find that the values of the volume of biogas produced by the anaerobic digestion process of the cow dung sample were fluctuating and amounted to The highest average volume of biogas produced was 268 litres/on the fiftieth day, then it decreased again, reaching 84 litres/on the eighty-eighth day, with a daily rate of 22.44 litres/40 kg/day, i.e. an amount of 0.56 one litres/one kilogram/day as shown in the Table 1.

The fluctuation in biogas production over the days could be due to various factors such as the change in the characteristics of the anaerobic digester and ambient conditions such as wet and dry temperatures, air temperature, and pH, as shown in this study, Table 1. Despite fluctuations, an upward trend in productivity can be observed around the middle of the period, and then productivity begins to decline.

**Treatment (C): Biogas Production from the Mixture (Food Scraps and Cow Manure):** Figure 9 and Table 1 show the cumulative production of biogas during the digestion period of 22 days, which amounted to 697 liters/40 kg in treatment (C). We find that the volume values of biogas produced by the anaerobic digestion process of the mixture sample gradually increased from Zero, reaching its peak on the tenth day, when the amount of biogas produced reached 233 liters, then

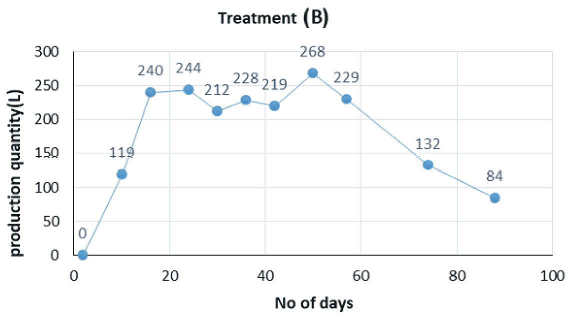


Fig. 8: Quantity of methane gas production (litres) / 40 kg biomass.

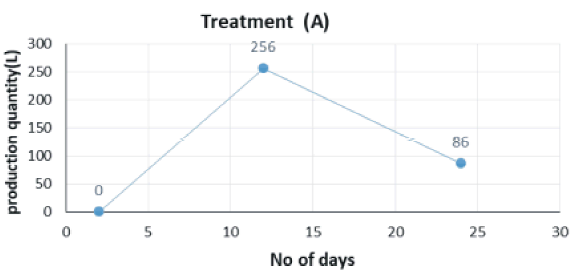


Fig. 9: Quantity of methane gas production (litres) / 40 kg biomass

decreased again, reaching 77 liters on the twenty-second day, at a rate of 31.68 liters/40 kg/day, i.e. an amount of 0.79 liters/one kilogram/day, as shown in the Table 1.

**Statistical Analysis in the Study:** The results of the analysis of variance in Table 1 indicated that there were statistically significant differences with highly significant differences between organic household waste, cow manure, and the mixture in wet temperature, air temperature, and pH, while there were no significant differences in dry temperature.

Table 1 shows that there were significant differences in wet temperature, and the highest rates were reported in cow manure treatment (B), where the average temperature reached 37.5, and organic household waste treatment (A), which was 36.8, while treatment (C) which is a mixture (food leftovers and cow manure) had the lowest average at the wet temperature of 36.3. It can be also noted that the significant differences were evident between the averages of cow manure and the mixture, but no statistically significant differences were found between household waste and cow manure treatments.

The reason behind the high humid temperatures during anaerobic digestion of cow manure sample is the biological activity of methanogenic bacteria. These bacteria work to break down organic materials in the dung under conditions of absence of oxygen, leading to the secretion of methane gas. This process requires specialized ambient preparation that includes high humid temperatures, which positively affects the activity of bacteria and the speed of the process of formation and release of methane gas.

Table 1 also shows that there are no significant differences in dry temperature. The highest rates were in treatment (B), which is (cow manure), where the average temperature reached 36.5, and treatment (C), which is a mixture of (food scraps and cow manure), was 36.3. Treatment (A) (organic household waste) had the lowest average dry temperature of 36.2. The reason for the lack of significant differences in dry temperatures for methane production is based on the adaptation of methanogenic bacteria to a specific temperature. These bacteria appear to be able to adapt effectively to changes in their surrounding environment, allowing them to grow and stabilize within a specific range of dry temperatures. This ability to adapt comes as a mechanism that contributes to reducing the effect of fluctuations in dry temperatures on the rate of methane production. Therefore, adaptation can reduce significant differences and make production stable despite changes in dry temperatures. Table 1 also shows that there are significant differences in the average air temperature, and its highest rates were recorded in treatment (C), which is a mixture of (food scraps and cow manure), it reached 31.4, and treatment (A), which is (organic household waste), was 30.7, while Treatment (B) (cow manure ) recorded the lowest average with air temperature of 30.4. We note that there were significant differences between the means of the mixture and cow manure, but there were no differences between household waste and cow manure.

The results of Table 1 also confirmed the presence of significant differences in pH, which reached the highest rates in treatment B (cow manure ), where the pH average reached 6.6, and treatment (C), which is a mixture ( Food scraps and cow manure ) scored 5.4, while treatment (A) (organic household waste) got the lowest average of 3.7. There were significant differences among all treatments . The reason for the high pH in the cow manure sample is due to the activity of methanogenic bacteria during the anaerobic digestion process. The decomposition of organic materials can lead to the production of hydrogen during the digestion stage, but this process usually leads to a decrease in the pH due to the production of volatile acids but not its increment since the process of producing hydrogen through acid generation tends to acidify the environment, not alkaline it [22]. Several investigators confirmed these findings [23-26].

Table 1: The effect of biomass treatments (A, B, C) on wet, dry air temperatures, pH values and Methane gas production during the experiment period

| Treatments | Duration ( day) | Temperature (air) | Temperature (humid) | Temperature (dry) | pH | Methane gas production (Litre) L/treatment | L/day | L/kg |
|---|---|---|---|---|---|---|---|---|
| Domestic waste (A) | 32 | 30.7b | 36.8ab | 36.2a | 3.7c | 342c | 10.7c | 0.27c |
| Cow manure (B) | 88 | 30.4b | 37.5a | 36.5a | 6.6a | 1975a | 22.4b | 0.56b |
| Mixture (C) | 22 | 31.4a | 36.3b | 36.3a | 5.4b | 697b | 31.6a | 0.79a |
| Significance p< 0.05 | | ** | ** | Ns | ** | ** | ** | ** |

The results in the columns with different letters indicate significant differences at statistical probability / P = 0.05.

## REFERENCES


1. Omar Saadi, Ali Fares and Ramadan A. M Alhendawi, 2008. Book: Introduction to natural resources. Omar Al-Mukhtar University Publications - Libya - First Edition - 2008.
2. Kumar, S., S. Jain and R.K. Singh, 2021. Environmental Impacts of Fossil Fuels. In Handbook of Environmental Materials Management (pp: 1-24). Springer.
3. Kabir Muhammad, Habiba Um E., Khan Wali and Rahim Sarvat, 2023. Climate change due to increasing concentration of carbon dioxide and its impacts on environment in 21st century; a mini review. Published by Elsevier B.V. on behalf of King Saud University. CrossRef DOI link to publisher maintained version: https://doi.org/10.1016/j.jksus.2023.102693
4. EIA., 2021. International Energy Outlook 2021. U.S. Energy Information Administration.
5. REN21, 2021. Renewables 2021 Global Status Report. Renewable Energy Policy Network for the 21st Century.
6. Patrick Moriarty ORCID, (2022). Can Bioenergy Once again Become a Major Global Energy Source. Encyclopedia 2022, 2(3): 1357-1369; https://doi.org/10.3390/encyclopedia2030091
7. Jang, H.M., J.H. Ha, D.H. Kim and H.S. Kim, 2018. Evaluation of methane production from food waste leachate with high strength in anaerobic digestion process. Journal of Environmental Management, 206: 1190-1195.
8. Hossain, M.K., and M. Fujimoto, 2011. Methane production from livestock manure: a review. Renewable and sustainable energy reviews, 15(7): 3295-3304.
9. Haider, M.R., Zeshan Sohail Y., R.N. Malik and C. Visvanathan, 2015. Effect of mixing ratio of food waste and rice husk co-digestion and substrate to inoculum ratio on biogas production. Bioresource Technology, 190: 451-45.
10. Hassan, M.A.M., 2004. The Feasibility of Family Biogas Production from Mixed Organic Wastes in Palestinian Rural Areas. An-Najah National University Faculty of Graduated Studies. M.Sc. thesis.
11. Ball, D., 2011. Introductory Chemistry Saylor Foundation.
12. Gomez, K.A. and A.A. Gomez, 1984. Statistical procedure for agricultural research. John Wiley and Sons. J. Agril. Res., 50(3): 357-364.
13. Li, X., and N. Shimizu, 2023. Biochar-promoted methane production and mitigation of acidification during thermophilic anaerobic co-digestion of food waste with crude glycerol: comparison with re-inoculation. Sustainable Environment Research, 33(4).
14. Liu, C., A.C. Wachemo, H. Tong, S. Shi, L. Zhang, H. Yuan and X. Li, 2018. Biogas production and microbial community properties during anaerobic digestion of corn stover at different temperatures. Bioresource Technology, 261: 93-103.
15. Pasalari, H., M. Gholami, A. Rezaee, A. Esrafili and M. Farzadkia, 2021. Perspectives on microbial community in anaerobic digestion with emphasis on environmental parameters: A systematic review. Chemosphere, 270: 128618.
16. Mao, C., T. Zhang, X. Wang, Y. Feng, G. Ren and G. Yang, 2017. Process performance and methane production optimizing of anaerobic co-digestion of swine manure and corn straw. Scientific Reports, 7(1).
17. Babaee, A., J. Shayegan and A. Roshani, 2013. Anaerobic slurry co-digestion of poultry manure and straw: effect of organic loading and temperature. Journal of Environmental Health Science and Engineering, 11(1): 15. doi:10.1186/2052-336X-11-15
18. Nie, E., P. He, H. Zhang, L. Hao and L. Shao, 2021. How does temperature regulate anaerobic digestion? Renewable & Sustainable Energy Reviews, 150: 111453.

19. Shu, C., R. Jaiswal, M. Kuo and B. Yu, 2022. Enhancing methane production in a Two-Stage anaerobic digestion of spent mushroom substrate and chicken manure via activation of sludge, optimization of temperature, and C/N ratio. Frontiers in Environmental Science, 9.
20. Gaby, J.C., M. Zamanzadeh and S.J. Horn, 2017. The effect of temperature and retention time on methane production and microbial community composition in staged anaerobic digesters fed with food waste. Biotechnology for Biofuels, 10(1).
21. Zhang, C., H. Su, J. Baeyens and T. Tan, 2014. Review of the anaerobic digestion of food waste. Renewable and Sustainable Energy Reviews, 38: 383-392.
22. Arslan, C., A. Sattar, J. Changying, A. Nasir, I.A. Mari and M.Z. Bakht, 2015. Impact of pH Management Interval on Biohydrogen Production from Organic Fraction of Municipal Solid Wastes by Mesophilic Thermophilic Anaerobic Codigestion. BioMed Research International, pp: 1-9.
23. Budiyono, I. and S. Sumardiono, 2013. Biogas Production Kinetic from Vinasse Waste in Batch Mode Anaerobic Digestion. World Applied Sciences Journal, 26(11): 1464-1472.
24. 24. Ruhi, R.A., N.J. Methela, A.F. Sultana Eti and C.K. Saha, 2019. Conversion of Agricultural Waste (Maize) Into Energy Using Biogas Technology. American-Eurasian J. Agric. & Environ. Sci., 19 (5): 343-349 .
25. Abanades, S., H. Abbaspour, A. Ahmadi, B. Das, M.A. Ehyaei, F. Esmaeilion, M. El Haj Assad, T. Hajilounezhad, D.H. Jamali, A. Hmida, H.A. Ozgoli, S. Safari, M. AlShabi and E.H. Bani-Hani, 2022. A critical review of biogas production and usage with legislations framework across the globe. Int. J. Environ. Sci. Technol. (Tehran), 19(4): 3377-3400. doi: 10.1007/s13762-021-03301-6. Epub 2021 May 16. PMID: 34025745; PMCID: PMC8124099.
26. Singh, A.K., P. Pal, S.S. Rathore, U.K. Sahoo, P.K. Sarangi, P. Prus, P. Dzieka ´nski, 2023. Sustainable Utilization of Biowaste Resources for Biogas Production to Meet Rural Bioenergy Requirements. Energies 2023, 16, 5409. https://doi.org/10.3390/en16145409