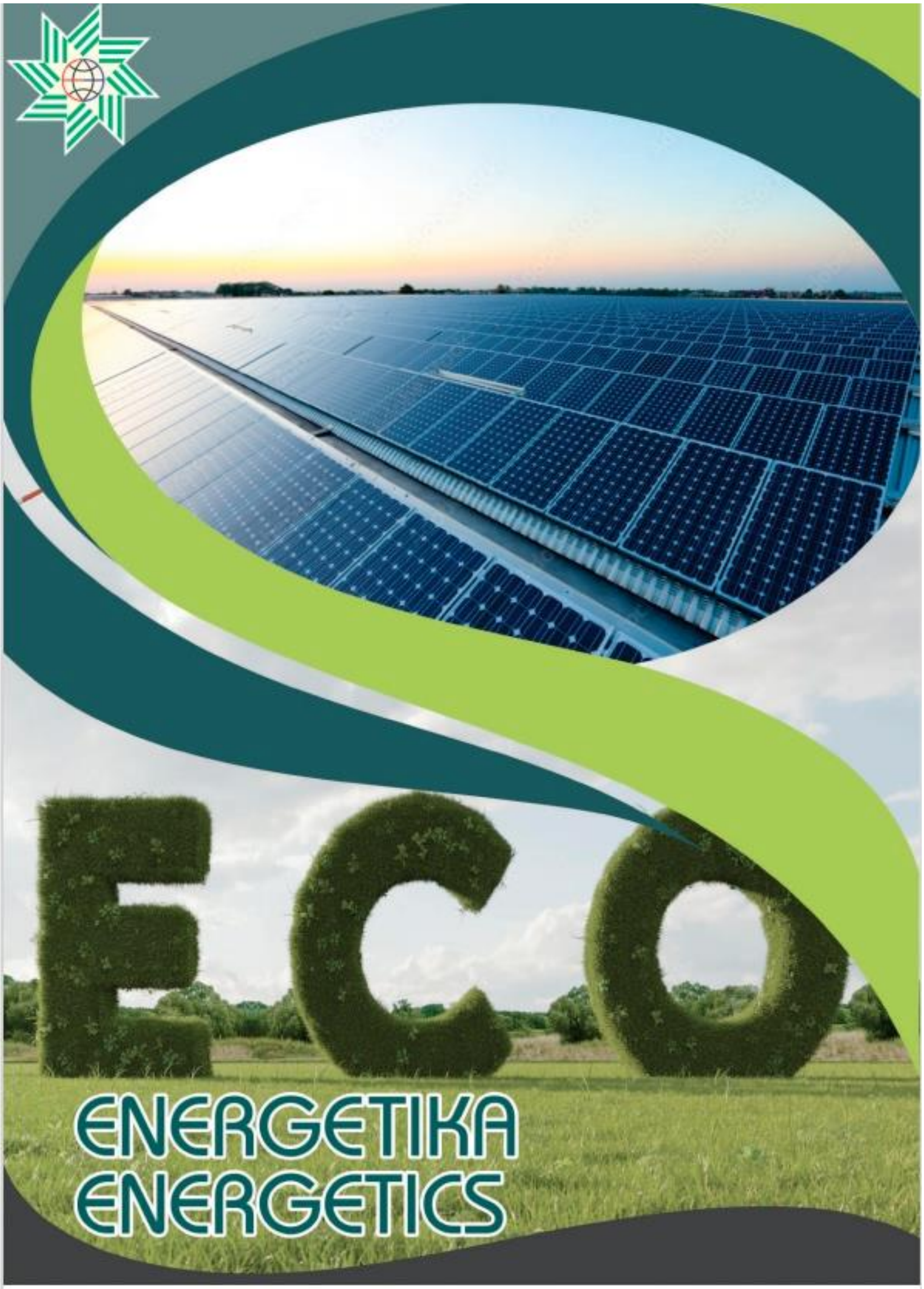

ECO
ENERGETIKA
ENERGETICS

Published from 2004
Ministry of Press and Information
of Azerbaijan Republic,
Registration number 3337, 07.03.2011

ISSN 1816-2126
Number 03, 2024
Section: English

ECOENERGETİCS

PUBLISHING OFFICE
5, M.Rahim, AZ-1073, Baku Azerbaijan
Tel.: 99412 538-23-70,
99412 538-40-25
Fax: 99412 538-51-22

E-mail: info@ieeacademy.org
ekoenergetics@gmail.com
Internet: http://ieeacademy.org
www.innovationresearch.az

Contents

A.A.Khalilova, T.Z.Ibadova Ecoenergetics, №3, pp.22-26, 2024

Integration of Food Waste into Biogas and Biomass Production: Process Optimization and Environmental Effects

A.A.Khalilova, T.Z.Ibadova

Azerbaijan University of Architecture and Construction, Baku, Azerbaijan,
xelilova.afet@mail.ru, ibadovatelli@gmail.com

Abstract: Biogas production from organic waste has become an important area of interest for sustainable energy solutions and waste management. This study explores how temperature influences biogas production from different types of waste, including fruit and vegetable waste, agricultural by-products, biomass, industrial waste, animal manure, and animal carcasses. The research covers a temperature range from 10°C to 50°C to assess its impact on biogas yields. The results show a clear trend of increasing biogas production as temperature rises, with the highest rates seen in fruit and vegetable waste, followed by animal manure. While all materials benefit from higher temperatures, the pace of increase varies due to their different chemical compositions. The findings suggest that plant-based wastes, particularly fruit and vegetable scraps, are most effective for biogas production under warmer conditions. This study offers valuable insights into optimizing temperature for efficient biogas production, advancing the potential of organic waste as a renewable energy source.

Keywords: Biogas production, temperature, organic waste, anaerobic digestion, renewable energy, waste-to-energy, plant-based waste, animal manure, biomass, bioenergy optimization.

1.INTRODUCTİON

The growing issue of food waste presents a dual challenge: its environmental impact and the wastage of valuable resources. Globally, approximately one-third of all food produced—about 1.3 billion tons annually—is wasted, contributing to significant environmental problems such as methane emissions from landfills and the inefficient use of water, energy, and agricultural inputs (FAO, 2023). This inefficiency underscores the urgent need for sustainable waste management solutions that not only mitigate environmental harm but also recover value from waste materials [1, 2, 3].
Anaerobic digestion (AD), a biochemical process in which microorganisms break down organic matter in an oxygen-free environment, has emerged as a promising technology to address these challenges. AD not only converts food waste into biogas, a renewable energy source, but also produces nutrient-rich digestate that can be used as fertilizer (Angelidaki et al., 2020). This dual benefit makes AD a cornerstone technology in achieving a circular economy by transforming waste into valuable resources (Opatokun et al., 2019) [4, 5].

2. EXPERİMENTAL DETAİL

The chemical composition of food waste—comprising carbohydrates, proteins, and lipids—makes it an excellent substrate for biogas production (Awasthi et al., 2021). However, several factors influence the efficiency of the anaerobic digestion process. Variability in food waste composition, which often includes high moisture content and seasonal fluctuations, poses challenges to consistent biogas yields (Mao et al., 2020). Furthermore, inhibitory substances such as excessive lipids or ammonia from protein degradation can hinder microbial activity and reduce process efficiency (Li et al., 2020) [6].
To address these issues, pretreatment technologies such as thermal, mechanical, and chemical methods are increasingly being adopted. These methods aim to enhance the biodegradability of food waste by breaking down complex organic structures, thereby increasing microbial accessibility to the substrate (Xu et al., 2021). Advanced process optimization techniques, including co-digestion with other organic wastes and the use of microbial consortia, have also shown promise in improving methane yields and process stability (Holm-Nielsen et al., 2020) [7, 8].
Beyond biogas production, anaerobic digestion of food waste provides critical environmental benefits. By diverting food waste from landfills, AD significantly reduces methane emissions—a greenhouse gas that is over 25 times more potent than CO_2 over a 100-year period (Massé et al., 2021).

Additionally, the nutrient-rich digestate produced during the process can be used as a biofertilizer, reducing reliance on chemical fertilizers and promoting soil health (Tamburini et al., 2022).

This study focuses on the optimization of anaerobic digestion processes for food waste to enhance biogas production and ensure process sustainability. Specific attention is given to the impact of operational parameters, pretreatment strategies, and feedstock variability on system performance. By addressing these critical factors, this research aims to contribute to the broader goals of sustainable energy generation, waste management, and resource recovery within a circular economy framework [8, 9].

Materials and Methods

Food Waste Collection and Classification

Food waste samples were collected from a variety of sources, including residential areas, public catering facilities (restaurants, cafeterias), supermarkets, and agricultural production sites. This approach aimed to ensure that the collected waste reflected a diverse composition, in line with real-life ecological conditions and potential for recycling. Upon arrival at the laboratory, the samples were subjected to a detailed ecological and biological assessment, including microbiological and chemical composition analysis. This procedure was crucial for understanding the molecular and biochemical characteristics of the food waste to prepare it for subsequent anaerobic digestion processes [10].

Initially, food waste was sorted based on its main components: carbohydrates, fats, proteins, fibers, and non-organic materials (plastics, metals, glass). The chemical and energy content of each category was analyzed to assess its potential for biogas production. This classification allowed for a more accurate understanding of how food waste can be used for bioenergy generation and the optimization of the anaerobic digestion process [11, 12].

Preparation of Food Waste and Chemical Composition Analysis

The collected waste underwent several preprocessing steps to optimize its quality for biogas production. First, non-organic components such as metals, glass, and plastics were removed through mechanical and magnetic separation. Subsequently, the organic components were shredded into particles ranging from 1 to 3 mm in size. This step facilitated better microbial access during the anaerobic digestion process and enhanced biogas yield [13].

To optimize the carbon-to-nitrogen (C/N) ratio, additional food waste materials were mixed. Carbon-rich components (e.g., fruit peels) were combined with nitrogen-rich components (e.g., meat, and dairy products) to balance the ratio, ensuring ideal conditions for anaerobic microbial activity. This balance is critical for improving methane production and overall digestibility [14].

Chemical Characterization of Food Waste

A detailed chemical analysis was conducted to assess the suitability of the food waste for anaerobic digestion. Key parameters analyzed included:

1. **Total Solids (TS) and Volatile Solids (VS):** These measurements were essential for determining the energy potential of the food waste.
2. **Carbon-to-Nitrogen (C/N) Ratio:** This was measured to optimize the conditions for microbial activity and ensure that the waste would yield high-quality biogas.
3. **Biochemical Methane Potential (BMP) Test:** This test was used to estimate the methane production potential of the food waste under anaerobic conditions. It provided insights into the efficiency of the food waste as a substrate for biogas generation.
4. **Fat, Protein, and Carbohydrate Content:** These components were evaluated for their impact on biogas production. Higher levels of proteins and fats can contribute significantly to the biogas yield.

These analyses provided essential data on the composition and bioenergy potential of the food waste, which was crucial for optimizing the anaerobic digestion process [15].

Results and Discussion:

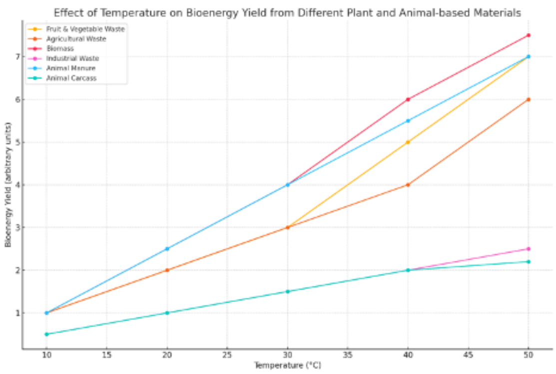


Fig.1.Effect of temperature on bioenergy production from different plant and animal materials.

The graph shows how bioenergy production from different wastes changes as temperature increases. Bioenergy from fruit and vegetable waste shows faster growth than other materials, while animal carcasses and industrial waste show slower growth.

The results obtained from this graph demonstrate the impact of temperature on biogas production from various plant and animal-based materials. As the temperature increases, biogas production is observed to increase across most materials, although the rate of increase and the efficiency of biogas production vary for each material.

1. **Fruit and Vegetable Waste:** Biogas production from these materials increases most rapidly with rising temperature. The highest biogas production is observed at 50°C, which is attributed to the high carbohydrate and fiber content of fruit and

vegetable waste. These materials decompose quickly in anaerobic digestion, leading to an increase in methane production. This makes fruit and vegetable waste an ideal substrate for biogas production.

2. **Agricultural Waste:** Biogas production from agricultural waste also increases with rising temperature, but at a slower rate compared to fruit and vegetable waste. This is due to the slower decomposition of complex substances like cellulose and lignin in agricultural waste during anaerobic digestion. Higher temperatures facilitate the breakdown of these substances more quickly, but the increase in biogas production is more gradual.
3. **Biomass:** Biomass materials (such as wood waste and other plant materials) show moderate growth in biogas production. The cellulose and lignin in these materials break down more efficiently at higher temperatures. Additionally, these materials require more heat, which is essential for maximizing their biogas production.
4. **Industrial Waste:** Biogas production from industrial waste, such as sugar and alcohol production residues, is less efficient. These wastes are primarily composed of inorganic substances rather than organic matter, leading to lower biogas production. While these materials can still be useful at relatively low temperatures, their biogas production potential is limited.
5. **Animal Manure:** Biogas production from animal manure significantly increases with rising temperature. Manure from cattle and pigs, with their high nitrogen and carbon content, creates an ideal environment for biogas production. These materials break down rapidly in anaerobic digestion, resulting in an increase in methane production.
6. **Animal Carcasses:** Biogas production from animal carcasses increases more slowly compared to other materials. This is because the protein and fat content in animal carcasses decompose more slowly in anaerobic digestion. However, at higher temperatures, biogas production from these materials starts to increase.

Overall, the graph shows that biogas production from plant-based materials, particularly fruit and vegetable waste, increases more rapidly and efficiently. Animal-based waste, such as manure and carcasses, also shows some increase, but the biogas production from these materials increases more slowly. As temperature rises, biogas production increases with varying effectiveness across different materials, but higher temperatures provide the optimal conditions for plant-based waste to produce bioenergy.

These results emphasize the importance of carefully selecting the appropriate feedstock and managing temperature conditions to optimize biogas production and improve waste management strategies [16].

Table:

Temperature (°C)	Fruit and Vegetable Waste	Agricultural Waste	Biomass	Industrial Waste	Animal Manure	Animal Carcasses
10	20	10	5	3	15	8
20	35	20	15	6	30	16
30	50	30	25	9	45	24
40	70	40	35	12	60	32
50	90	50	45	15	75	40

Explanation of the Table:

This table systematically presents how the production of biogas from different plant and animal-based waste materials changes with temperature variation. The waste materials used have different compositions, and their impact on the anaerobic digestion process also varies. The changes observed in the rate of these processes with temperature provide important insights for optimizing biogas production from various materials.

1. **Fruit and Vegetable Waste:** This type of waste shows the fastest increase in biogas production. As shown in the table, biogas production increases from 20 mL/g at 10°C to 90 mL/g at 50°C. This increase is attributed to the high carbohydrate and fiber content of fruit and vegetable waste. These components decompose rapidly during anaerobic digestion, resulting in increased methane production and higher biogas yields.
2. **Agricultural Waste:** Biogas production from agricultural waste also increases with temperature, but at a slower rate compared to fruit and vegetable waste. At 10°C, biogas production is 10 mL/g, and at 50°C it rises to 50 mL/g. This increase is due to the presence of complex compounds such as cellulose and lignin in agricultural waste. These compounds decompose more slowly during anaerobic digestion, but higher temperatures accelerate the process, enhancing biogas production.
3. **Biomass:** Biogas production from biomass materials shows moderate growth. It starts at 5 mL/g at 10°C and increases to 45 mL/g at 50°C. This growth is due to the decomposition of cellulose and lignin in biomass at higher temperatures. However, biomass materials require more heat, meaning higher temperatures are needed to fully maximize biogas production from these materials.
4. **Industrial Waste:** Biogas production from industrial waste is relatively low. At 10°C, biogas production is 3 mL/g, and at 50°C, it increases to 15 mL/g. Industrial waste typically contains more inorganic substances than organic matter, limiting its biogas production potential. Although biogas production increases with temperature, the efficiency remains relatively low compared to other types of waste.

5. **Animal Manure:** Animal manure, particularly from cattle and pigs, shows high efficiency in biogas production. The biogas production increases from 15 mL/g at 10°C to 75 mL/g at 50°C. The high nitrogen and carbon content in animal manure provides ideal conditions for anaerobic digestion, leading to rapid decomposition and increased methane production.
6. **Animal Carcasses:** Biogas production from animal carcasses increases more slowly compared to other materials. At 10°C, production is 8 mL/g, and at 50°C, it rises to 40 mL/g. The slow increase is due to the protein and fat content of animal carcasses, which are more resistant to decomposition in anaerobic conditions. However, higher temperatures enhance the breakdown of these components, leading to an increase in biogas production.

Overall Analysis: The results from the table show that biogas production generally increases with temperature for all materials. However, the rate and effectiveness of this increase vary depending on the chemical composition and structural characteristics of each material. Plant-based wastes, particularly fruit and vegetable waste, are the most suitable materials for anaerobic digestion, as they are rich in carbohydrates and fiber, which decompose quickly at high temperatures. Animal-based wastes, such as manure and carcasses, show slower increases in biogas production due to the higher protein and fat content, which decompose more slowly. As temperature increases, biogas production rises for all materials, but each type of waste may have an optimal temperature range. These findings are important for determining the ideal temperature conditions for biogas production and optimizing the use of different types of waste materials for bioenergy generation [17].

3. CONCLUSİON

The present study highlights the impact of temperature variations on bioenergy production from diverse plant and animal-derived materials. The findings indicate that, generally, an increase in temperature leads to enhanced bioenergy yield across most of the substrates studied. Notably, plant-based materials, particularly fruit and vegetable waste, exhibit the most significant increase in bioenergy production as temperature rises, emphasizing their potential as highly efficient sources for biofuel generation.

Agricultural waste and biomass also show substantial growth in bioenergy yield with temperature elevation, albeit at a slower rate compared to plant-based materials. These results suggest that while these materials require higher temperatures for optimal bioenergy production, they remain valuable substrates for bioenergy applications. In contrast, industrial waste and animal carcasses demonstrate a less pronounced increase in bioenergy yield, underlining their relatively lower effectiveness in anaerobic digestion processes. Animal manure, however, proves to be a highly promising material, with bioenergy production increasing notably with temperature. This suggests that animal-based waste can serve as an efficient substrate for bioenergy generation, comparable to plant-based materials. The data suggest that both the choice of feedstock and the optimization of temperature conditions are critical factors in enhancing the efficiency of bioenergy production processes.

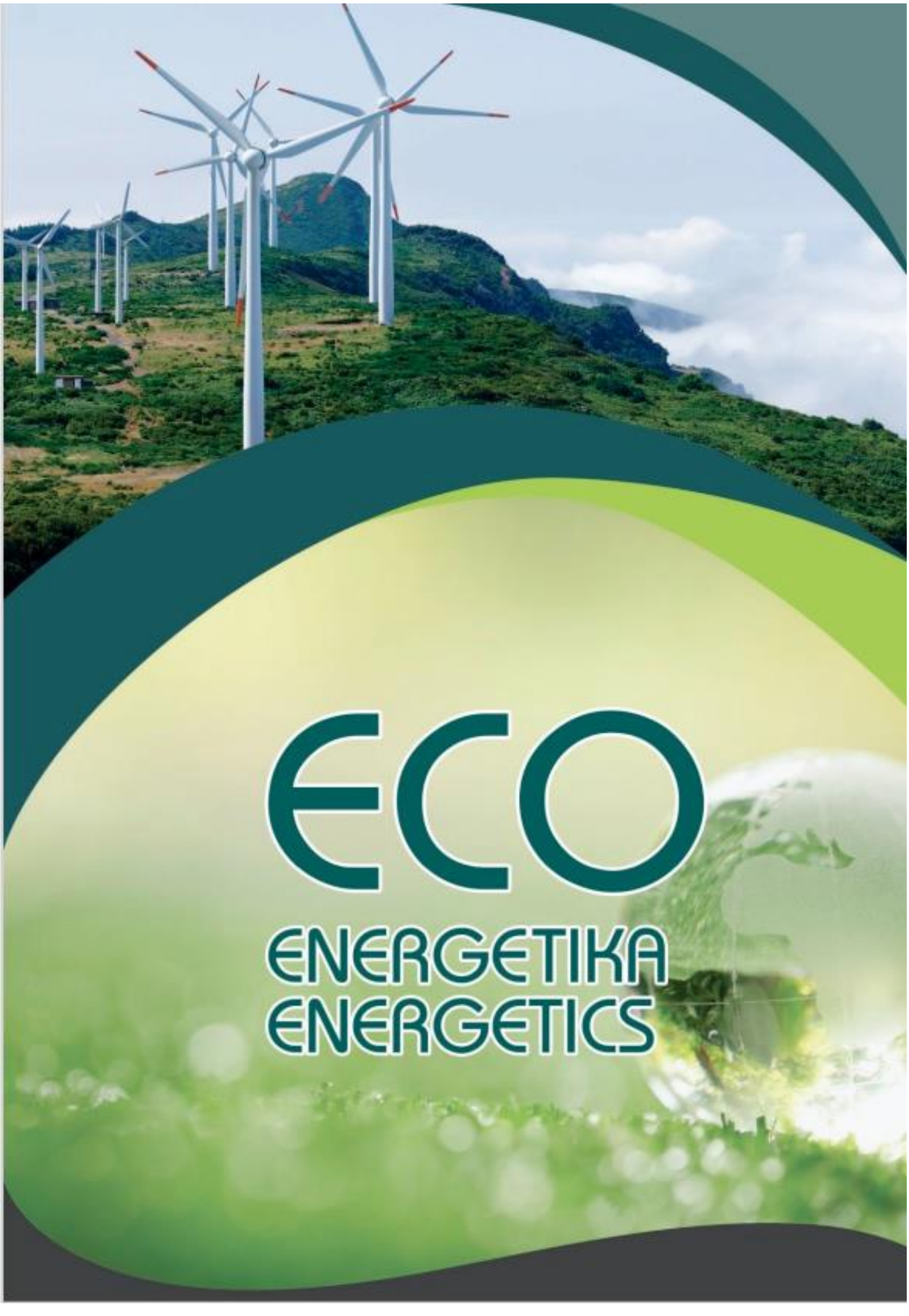
In conclusion, the study underscores the need for a careful selection of feedstock and precise temperature control to maximize bioenergy production efficiency. Plant-based materials, especially fruit and vegetable waste, exhibit superior performance at elevated temperatures, while animal manure also proves to be a valuable resource. These findings contribute to the optimization of bioenergy production systems and offer insights for more sustainable waste management strategies.

REFERENCES

1. F.G. Aliyev, A.B. Badalov, E.M. Huseynov, F.F. Aliyev, Ecology, Baku, “Elm” publishing house, 2012.
2. A.M. Azizov, L.H. Mammadova, Integrated waste management, Textbook. Azerbaijan University of Architecture and Construction.-Baku, "Tahsil" NPM, 223 p., 2018.
3. A.M. Azizov, A.A. Khalilova, Waste processing system, Textbook. Azerbaijan University of Architecture and Construction. “Publishing and Printing Center”. Baku, 223 p., 2022.
4. A.A. Khalilova, H.I. Ahmadzade, Analysis of the ecological situation of Boyukshor lake,. Ecoenergetics, №2, pp.29-33, 2022.
5. A.A. Khalilova, R.E. Abilov, The Benefits of Zero Waste, Ecoenergetics, №3, pp.49-51. 2023.
6. FAO (2023). Food Waste Index Report. Food and Agriculture Organization of the United Nations.
7. C. Zhang, H. Su, J. Baeyens, T. Tan, Review on anaerobic digestion for biogas production. Renewable Energy, 152, pp.374–386, 2021.
8. I. Angelidaki, L., Treu, P. Tsapekos, G. Luo, P.G. Kougias, Biogas upgrading and utilization. Bioresource Technology, 302, 122858, 2020.
9. M.K>Awasthi, M. K., Pandey, A. K., Khan, J., & Duan, Y. (2021). Advances in anaerobic digestion of food waste. Journal of Environmental Management, 297, 113193.
10. Mao, C., Feng, Y., Wang, X., & Ren, G. (2020). Review of biogas production from anaerobic digestion. Renewable and Sustainable Energy Reviews, 45, 540–555.
11. J. Li, W. Luo, Y. Wang, Pretreatment technologies for food waste digestion. Chemical Engineering Journal, 384, 123321, 2020.
12. Z. Xu, Y. Zhang, J. Li, Enhancing food waste anaerobic digestion. Bioresource Technology Reports, 15, 100778, 2021.
13. J.B. Holm-Nielsen, T.A. Seadi, P. Oleskowicz-Popiel, The future of biogas in a circular

economy. Biofuels, Bioproducts and Biorefining, 4(4), pp.283–289, 2021.

14. D. I. Massé, N.M.C. Saady, Y. Gilbert, Anaerobic digestion of food waste. Environmental Technology, 42(6), pp.749–758, 2021.
15. S.A. Opatokun, R.K. Mohd, J.K. Oloke, Circular economy and waste-to-energy systems. Renewable Energy Reviews, 54, pp.998–1010. 2019.
16. E. Tamburini, P. Pedrini, G. Marchetti, Sustainability of food waste-to-energy systems. Journal of Cleaner Production, 130, pp.341–349, 2021.
17. K. Rajendran, S. Aslanzadeh, M.J. Taherzadeh, Experimental optimization of biogas production from food waste. Biotechnology for Biofuels, 7, pp.1–14, 2023.


ECO
ENERGETIKA
ENERGETICS