Protecting the Environment by Managing and Processing Animal Manures: The Effect of Raw Material (Cow and Chicken Manure) and Reactor Type for Improving and Maximizing Biogas Production

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Abstract

Biomass energy is a type of renewable energy and animal waste is one of the main resources for its production. Anaerobic digestion is a method for biological treatment of organic waste, which nowadays plays an important role in refining and reusing wet and degradable waste materials due to the production of environmentally friendly materials and energy recovery. The process of anaerobic digestion takes place in oxygen-free conditions inside reactors called anaerobic digesters and produces a substance called biogas. The purpose of this study is to investigate the effect of raw material type (cow and chicken manure) and the type of reactor (digester) on the biogas produced by measuring the amount of methane in the product. Three types of digester (metal, simple PVC and PVC with leachate rotation) with the same volume (10 Liter) were prepared. Equipment was installed on the digesters to measure the pH and volume of produced gas. The experiments were carried out in controlled temperature conditions (28–30 ºC) and in two stages. The first experiment was to load the digesters with cow excrement and the second experiment was to load the digesters with chicken excrement. In both experiments, the digesters were fed with 1.5 kg of animal manure and water with a ratio of 1:1. During a period of 60 days, the volume of biogas and methane produced was measured and recorded. The results showed that the amount of biogas produced from chicken waste is more than the amount obtained from cow waste. However, the amount of methane produced using cow excrement was more than that of chicken excrement. Also, the performance of PVC digester with leachate rotation was better than the other two digesters, which could be due to the mixing of raw materials in this type of digester.

1. Introduction

In general, energy is defined as the ability to do work. In other words, when an object does something, it means it has energy. Energy plays an important role in the daily life of people. Energy resources (total energy available for use) are divided into two categories: non-renewable energy (such as fossil fuels) and renewable energy (such as biofuels and biogas). Fossil fuels are resources such as oil, gas, coal, etc. These resources have gradually come to existence over hundreds of millions of years (François et al., 2023; Laherrère et al., 2022; Jahanbakhshi et al., 2021). In the process, dead plants and organisms have decayed and been buried under the ground. They have then been compressed by the pressure and internal heat of the earth. Fossil fuels provide about 80–90% of the world’s energy, and they are being depleted due to excessive consumption. Fossil fuels took approximately 400 million years to form. But mankind has used something like 80% of all the fossil fuels of the earth in only 60 years from 1960 to 2020 (Yi et al., 2023; Dar and Asif, 2023; Heidari-Maleni et al., 2021).

Biomass is one of the important sources of renewable energy that is obtained from biological materials. Biomass usually includes organic matter that is used to produce electricity or heat (Venugopal, 2022; Jiang et al., 2023). Biological materials include living organisms or their remains. For example, the remains of forest trees, pruned materials from plants and wood chips, animal waste, animal droppings, agricultural product waste, urban waste and food waste can be used as biomass. These materials have the ability to store energy. In fact, during the photosynthesis phenomenon, carbon dioxide is stored in
plants through water, soil and air by solar energy and causes their growth and development. This solar energy can be converted into other forms of consumable energy later. Biomass is able to produce electricity, heat, liquid fuels, and gaseous fuels (biogas) and can have various useful chemical applications (Dutta et al., 2023; Periyasamy et al., 2023; Kumar & Agrawal, 2020; Jahanbakhshi & Salehi, 2019).

Biogas is a renewable natural energy source that leaves positive effects on nature and industries. This gas is produced from the decomposition of organic materials, including animal manure, food waste and sewage (Shaibur et al., 2021; Wardle et al., 2021). Manure and waste produce biogas through anaerobic digestion (that is, without the presence of oxygen). About 50–70% of biogas consists of methane and thus it is flammable. Biogas fuel is produced from the combination of methane, hydrogen, and carbon monoxide gases with oxygen, and 21% of air is oxygen. Biogas is the most economical renewable fuel that is used in many countries. This fuel is used for cooking, cooling and heating, electricity generation, waste management, and mechanical power generation (Czekala et al., 2023; Caetano et al., 2022; Fazzino et al., 2021).

The increasing need to obtain biofuels against fossil fuels has created a great interest in producing biogas from biomass sources. Using the anaerobic digestion method to produce biogas is the best way to recover biomass into energy. This technology is used as an effective and reliable method to produce biogas from various organic wastes (such as animal manure, agricultural waste, municipal sewage, etc.). Organic waste left in the environment is an important source of greenhouse gas emissions (such as methane and carbon dioxide). Now, if the methane produced in the process of anaerobic digestion of these wastes is controlled by a method, a large amount of global warming can be avoided. The only possible way to control methane emissions is to use closed vessels (anaerobic digesters) in which biomass is decomposed (Kunatsa and Xia, 2022; Bandgar et al., 2022; Vats et al., 2020). Methane can be used to generate heat, electricity and vehicle fuel. Methane production from organic materials mainly depends on the amount of materials in them that can be decomposed into CH$_4$ and CO$_2$. The fuel value of the produced biogas depends on the percentage of methane, the higher the amount of methane gas, the greater the ability of biogas. There are various types of digesters for anaerobic digestion of organic waste. Anaerobic digestion of organic waste is performed in different digesters in a single-stage, double-stage and multi-stage manner (Yaqoob et al., 2021; Orlando and Borja, 2020; Vats et al., 2020).

It is essential that we use new sources of energy (such as biofuels) instead of fossil sources. New energy systems in the future must rely on structural and fundamental changes in which carbon-free energy sources such as biomass are used. Biogas is one of those renewable energies that are often wasted. In addition to energy production, biogas is able to produce agricultural fertilizers and thus increase the public health level of a society as a disease control measure. Biogas is also a suitable solution for solid waste disposal (Heidari-Maleni et al., 2023; Alao et al., 2022). On the other hand, the accumulation of excreta in animal and livestock keeping centers for long periods of time causes the increase of insects and the transmission of various pollutants to the livestock environment and residential areas. Also, the strong smell of excrement attracts the attention of insects from faraway places to the environment of
livestock farms, hence, the possibility of transmission of contamination and animal diseases from other places. Another problem with accumulation of waste in one place is contamination of surface and underground water, which would in turn cause heavy damages to the environment. The use of animal manure in agricultural fields can transmit the disease to other animals in the region if the animal is sick or infected with parasites. However, in addition to producing a significant amount of gas, the use of anaerobic fermentation in animal husbandry creates a healthy environment for animals and human beings. The main flammable element of biogas is methane. Increase in CO$_2$ of the biogas mixture reduces its calorific value and flammability. In this study, we examine the effect of the type of raw material and reactor on improving biogas production. This piece of research pursues the following goals:

1) Management of animal manure and their processing for biogas production.

2) Evaluation and comparison of cow and chicken manure to improving and maximizing biogas production.

3) Evaluation and comparison of different digesters to improving and maximizing biogas production.

4) Investigating the effect of leachate circulation in biogas production.

5) Examining limitations, challenges and future research direction.

2. Materials and Methods

Figure 1 shows the stages of biogas production in this research.

2.1. Preparation of raw materials

In this research, cow and chicken manure were considered separately as raw materials for experiments and biogas production. To do so, cow and chicken manure were prepared fresh from cattle and poultry farms (Fig. 2).

2.2. Laboratory equipment for biogas production

To produce biogas, three types of digester (metal, simple PVC and PVC with leachate circulation) with the same volume of 10 liters were used.

2.2.1. Metal digester

An iron cylinder with a volume of 10 liters was used as the metal digester. After cleaning, painting and installing the required fittings, the digester was used for experiments (Fig. 3a).

2.2.2. Simple PVC digester

This digester has a volume of 10 liters. It consists of a cylinder, a top lid and a bottom lid, all with a diameter of 180 mm. On the top lid, pneumatic fittings are used to release gas. In the lower part of the
2.2.3. PVC digester with leachate circulation

The PVC digester with leachate circulation is double-walled and its volume is 10 liters (Fig. 4). A cylinder with a diameter of 160 mm and a height of 48 cm is used to make the outer wall of the digester. At the end of the digester, there is a 160 to 110 mm convertor, which is connected from the bottom to a 160 mm lid and from the top to the inner wall of the digester. The inner wall is a cylinder with a diameter of 110 mm. At the end of the inner cylinder, there is a 110 to 64 mm convertor. At the bottom of the digester, two plastic nets with a width of 5.5 cm and a height of 22 cm are installed on the wall of the inner cylinder. The plastic net (filter) prevents solid materials and coarse particles in the inner cylinder from entering the outer cylinder. The leachate of raw materials (cow and chicken manure) entered into the digester is placed between the two cylinders and it is the same liquid that circulates with the help of a pump (see Fig. 5). In the upper part of the digester, a 160 to 110 mm convertor is used, on which fittings for the gas outlet from the digester are installed.

In this research, in order to measure the effect of leachate circulation on the amount of biogas production, a PVC digester with a leachate circulation system was used. The internal structure of the digester makes it possible for the leachate to circulate and allows it to leave the internal filter and fall to the bottom of the digester. Also, the outlet built into the bottom of the digester allows the leachate to leave the digester. The circulation of leachate in this type of digester took place with the help of a pump (GP582 model, made in Iran). The pump was connected to a timer to let leachate circulation take place for a desired time. The timer was set to 999 seconds, and after this time, it was turned on for 3 seconds. Each time the pump was turned on, about 4 ml of leachate was moved inside the digester. The schematic of PVC digester with leachate recirculation system is presented in Fig. 5.

After preparing the digesters and installing the fittings on them, an air compressor device was used to test gas leakage from the digesters (Fig. 6).

2.3. Measuring percentage moisture content

To measure the percentage of moisture, a certain amount of cow and chicken manure was selected and weighed. Then the sample was placed in an oven with a 100 °C temperature for 4 hours. After taking the sample out of the oven, its final weight was measured. The experiment was replicated three times and the percentage of moisture was calculated using Eq. 1.

\[
\text{Moisture percentage} = \frac{W_0 - W_1}{W_0} \times 100
\]

1

2.4. Pre-treatment of raw materials
In similar studies, researchers have reported that pre-treatment of raw materials (such as animal manure, agricultural waste, urban waste, etc.) increases the yield and improves the biogas produced (Szwarc and Głowacka, 2021; Baştabak and Koçar, 2020). Therefore, in this study, the raw materials (cow and chicken manure) were pre-treated before loading the digesters, and thus indigestible solids such as rocks, plastic, metals, etc. were separated from the raw materials.

2.5. pH measurement

Before conducting the experiments, the pH of raw materials (cow and chicken manure) was measured. Then this measurement continued during the experiments to investigate the process of pH changes in the biogas production process. PH-220L model pH meter was used to measure the pH of raw materials (Fig. 7).

2.6. Collecting and measuring the produced biogas

Special bags were used to measure the volume of biogas produced (see Fig. 8). These bags were connected to the digesters by pneumatic fittings. To collect a higher volume of produced biogas, the bags were connected in series. Then, the gas inside the bags was measured and discharged by a 100 ml syringe at regular intervals (Fig. 9).

2.7. Measuring the amount of methane gas

The amount of methane in the produced biogas was determined using a gas measuring device (1702 GMAS model) (Fig. 10). Among the advantages of this device are the presence of simple equipment for gas analysis and the low cost of maintaining the device, which make it easier to work with compared to the equipment applying the gas chromatography method. The gas analyzer is equipped with a very sensitive sensor against low concentrations and is able to analyze and quantitatively detect methane gas in samples. Also, the device has the ability to connect to a computer, can save the results of gas measurements through a software and make them available to researchers.

2.8. Method of conducting experiments

In this research, in order to investigate the effect of the type of digester and the raw materials used (cow and chicken manure), in improving and maximizing biogas production, experiments were conducted in two phase. In the first phase of the experiments, the digesters (metal, simple PVC and PVC with leachate recirculation) were loaded with cow manure and in the second phase, the digesters were loaded with chicken manure. Each experiment was replicated three times in the 60-day timespan of the study. In each experiment, fresh cow and chicken manure was prepared from cattle and poultry farms and then pre-treated. In the next step, cow and chicken manure were mixed separately with water at a ratio of 1:1 (1.5 kg of water and 1.5 kg of manure). After ensuring no leakage, the digesters were loaded with the same amount of raw materials and the lid of the digesters was closed. In order to prevent the leakage of the produced biogas, the lid of the digesters was completely sealed with special glue. All experiments were performed at room temperature (28–30 ºC). During the tests, a thermometer was used to ensure that the
tests were carried out in the selected temperature range and the temperature changes as a variable did not affect the results of the test. The pH values of the raw materials were measured before loading them in the digesters and at certain intervals after loading. Also, in the 60-day timespan in this research, the amounts of methane gas as well as the biogas produced were measured in all digesters. At the end of the 60-day period, the digesters were emptied and prepared for reloading after washing.

2.10. Statistical analysis

A factorial experiment (2×3: manure type and digester type) with a randomized complete design was used to analyze the effect of manure type at two levels (cow and chicken manure) and digester type at three levels (metal, simple PVC and PVC with leachate rotation) each with three replications (18 treatments). The effect of each variable on the amount of biogas produced was analyzed. The mean of the treatments were compared using the Duncan test (p < 5%). SAS (version 9.1) software was used for statistical analysis.

3. Results and Discussion

3.1. Properties of raw materials

The properties of the materials used in this research (cow and chicken manure) are presented in Table 1. Knowing these properties enables us to find a suitable mixture of raw materials and water for loading in the digester tank. The data in Table 1 show that cow manure has the highest percentage of moisture (86.50%) and the lowest pH (8.12) compared to chicken manure.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Cow manure</th>
<th>Chicken manure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture percentage</td>
<td>86.50</td>
<td>51.00</td>
</tr>
<tr>
<td>pH</td>
<td>8.12</td>
<td>9.14</td>
</tr>
</tbody>
</table>

3.2. Statistical results

The results of variance analysis of the effect of the main factors (i.e. manure type and digester type) and their interaction (i.e., manure type × digester type) on the amount of biogas and methane produced are reported in Table 2. The results show that the effect of the main factors and their interaction is significant at the probability level of 1% in biogas production. Also, in methane production, the effect of the main factors was significant at the 1% probability level and their interaction (i.e., MT × DT) was significant at the 5% probability level. Significance at the probability level of 1% indicates that it can be said with 99% confidence that there is a significant difference between the average treatments.
Table 2
The results of variance analysis of the effect of the main factors and their interaction on the amount of biogas and methane production.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Measured adjectives</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F Value</th>
<th>Pr&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure type (MT)</td>
<td>Biogas</td>
<td>1</td>
<td>44670152.00</td>
<td>44670152.00**</td>
<td>16214.20</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>1</td>
<td>581786.05</td>
<td>581786.05**</td>
<td>365.81</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>Digester type (DT)</td>
<td>Biogas</td>
<td>2</td>
<td>430488007.00</td>
<td>215244003.50**</td>
<td>78128.50</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>2</td>
<td>237920.98</td>
<td>118960.49**</td>
<td>74.80</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td>MT × DT</td>
<td>Biogas</td>
<td>2</td>
<td>17094823.00</td>
<td>8547411.50**</td>
<td>3102.51</td>
<td>&lt; .0001</td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>2</td>
<td>16194.84</td>
<td>8097.42*</td>
<td>5.09</td>
<td>0.0251</td>
</tr>
</tbody>
</table>

Note: ** and * show significance at the probability level of 1% and 5%, respectively.

3.3. pH changes

pH is an important factor in the growth of microorganisms and a criterion for determining the level of stability in digesters. Methanogenic bacteria that participate in the fermentation process are sensitive to the pH of the environment. Methanogenic bacteria and other anaerobic organisms usually perform best in environments with a pH of 8-8.6 (Wang et al., 2023; Xie et al., 2023). During the experiments, the materials inside the digesters were sampled and the pH level was measured, and the results were reported in Fig. 11 and Fig. 12 for cow and chicken manure, respectively. The results in Fig. 11 indicate that the greatest amount of pH drop occurs in the first days after the start of the digestion process, due to the production of more acid and slow consumption by methanogens. But after that, due to the increase in alkalinity and buffering capacity of the system, the pH value has an almost stable trend. Until the 35th day, the pH value of the digester environment went through a decreasing trend, the reason of which could be the biological reaction of the substances inside the digesters.

The results reported in Fig. 12 show the changes in pH in the biogas production process using chicken manure. These results are similar to the results obtained for cow manure. The results from Fig. 11 and Fig. 12, show that the pH level in the PVC digester with leachate circulation is higher than the other two digesters. Therefore, it can be said that the higher pH is caused by the leachate circulation. Leachate circulation enables fatty acid consumption and increases the activity of methanogens in the digester and thus the pH decreases more slowly.

3.4. The amount of biogas produced

Figure 13 shows the amount of biogas produced daily (up to 60 days) in the process of anaerobic digestion of cow manure in different digesters. The results show that the microorganisms present in cow manure cause biogas production in the first days. But with the passage of time and due to the closed
environment of the digesters and the lack of entry of new raw materials, the amount of acids produced in the digesters increases. With the increase of acid in the digester environment, the proliferation and activity of bacteria, dependent on environmental conditions such as pH changes, decreases over time and leads to a decrease in biogas production. After that, being adapted to the environmental conditions, anaerobic microorganisms, especially methanogens, are able to grow and reproduce. Therefore, by consuming the acids produced in the digester, the amount of biogas produced increases.

The amount of biogas produced daily in the process of anaerobic digestion of chicken manure in different digesters is reported in Fig. 14. The data in Fig. 14 indicate that the micro-organisms in the chicken manure produced the largest amount of biogas in the first days. Chicken manure started the process of biogas production sooner and produced the highest amount of biogas by the 40th day. The results reported in Fig. 13 and Fig. 14 show that the amount of biogas production from cow and chicken manure in the PVC digester with leachate circulation is higher than the other two digesters, which could be due to the leachate circulation. It is because leachate circulation makes the materials inside the digester mix together.

The average total volume of biogas produced from cow and chicken manure using different digesters is presented in Fig. 15. The results show that the PVC digester with leachate circulation has the best performance in biogas production compared to other digesters. The circulation and mixing of materials inside the digester causes more microbial activities and produce more biogas. In addition, the amount of biogas production using chicken manure is higher than the amount produced through cow manure in different digesters. The highest amount of biogas production is related to chicken manure (27000 ml) and cow manure (27000 ml) in PVC digester with leachate circulation. The materials used in poultry food increase the organic matter in chicken manure and are easily decomposed by microorganisms. Therefore, the acceleration of the hydrolysis phase in the anaerobic digestion process increases the production of biogas using chicken manure compared to cow manure. These results are similar to the results reported by Rahimi-zadeh (2013).

### 3.5. The amount of methane gas produced

One of the goals of this research is to evaluate the amount of methane in biogas produced from cow and chicken manure. In Fig. 16, the average volume of methane produced using cow and chicken manure in different digesters is reported. The results show that cow manure produced higher amounts of methane compared to chicken manure. Among all the treatments, the highest amount of methane production related to cow manure where 1966.65 ml of it were obtained in the PVC digester with leachate circulation. The difference in the amount of methane obtained from cow manure compared to chicken manure is due to the food used in cattle farms, which contains fodder.

### 4. Environmental consequences
The first obvious environmental consequence is the use of biomass energy to produce an alternative and clean fuel (such as biogas) instead of fossil fuels and reducing the adverse environmental consequences of their consumption. The remaining waste after fermentation and biogas production from cow and chicken manure can be used as a rich and organic fertilizer in agricultural lands. Because this fertilizer, unlike fresh animal manures, has no smell and does not pollute the environment. Also, animal parasites and weed seeds are destroyed in this fertilizer and it has no attraction for the growth of harmful insects (such as flies, mosquitoes, etc.). Other positive environmental consequences of biomass energy can be examined in economic and social dimensions, which include (Ravi et al., 2023; Ai et al., 2020; Wang et al., 2023; Yerassyl et al., 2022):

- Generating income through the sale of energy (biogas, electricity and heat) and organic fertilizer that can be used in agriculture and green space development.
- Treatment of solid waste without long-term costs such as soil and water pollution.
- Optimization of soil and productivity in agriculture due to the use of organic fertilizer.
- Acquiring the technology to build biogas plants in the country and exporting it to other countries.
- Preventing the outflow of foreign currency due to the production of organic fertilizers to reduce the consumption of chemical fertilizers and to reduce the demand for chemical pesticides to control pests and weeds, as well as to reduce the demand for fossil fuels.
- Production of methane and CO$_2$ as industrial raw materials.
- Creating employment in the recycling sector as well as in the biogas production sector.
- Optimizing the health situation in villages and cities.

5. Challenges and obstacles

In Iran, due to having huge resources of fossil fuel and paying subsidies to the people, energy reaches the consumer at a low price. On the other hand, energy production from non-conventional sources (such as solar, wind and biomass) requires relatively high costs (see Fig. 17). In addition, even the costs of conventional energy (such as fossil fuels) are approximate and not real, and to calculate their real price, other costs should be considered, which are not considered in Iran. Another important point is that the change in the price of energy is a very complex issue and depends on various economic, political and social factors at the global level, and any change in the price of energy can lead to social and political crises. As a result, energy policy requires detailed and long-term expertise that will eventually pave the way for the production of clean and renewable energies (such as biogas). Also, in Fig. 18, the existing obstacles for the development and production of biogas in Iran are reported (Heidari-Maleni et al., 2023; Tavana et al., 2019).

6. Conclusion

Today, the energy crisis due to excessive use of fossil fuels in the world has led most countries and experts to the production and use of renewable energy. In this research, the effect of the type of raw
material and digester on the amount of biogas and methane production was investigated. In the first experiment, when the digesters were loaded with cow manure, the amounts of biogas produced in metal digesters, simple PVC, and PVC with leachate circulation were 14372, 11755, and 21097 ml, respectively. The results of the second experiment in which the digesters were loaded with chicken manure, showed that the amounts of biogas produced in metal digesters, simple PVC and PVC with leachate circulation were 16276, 13400 and 27000 ml, respectively. The highest amounts of methane production using cow and chicken manure were 1966.65 and 1534 ml respectively in PVC digester with leachate circulation. Based on the results, it can be said that chicken manure is superior to cow manure due to the presence of more organic matter in it and the production of more biogas by using it. Using a PVC digester with a leachate circulation system increases the efficiency of biogas production and the amount of methane obtained. The leachate circulation system can be a suitable alternative to using a stirrer in digesters (as the stirrer consumes a lot of energy). Moreover, the circulation of the leachate affects the pH, because it makes the consumption of fatty acids possible, increases the activity of methanogens in the digester, and prevents the drop of pH. From the results obtained in this research, it was proved that there are many raw materials (such as animal manure) and energies in nature, which can be recovered and used as an environmentally friendly biofuel (such as biogas) by identifying and applying appropriate technology and methods.

**Declarations**

**Ethical Approval:** This study does not involve any human or animal testing.

**Consent to Participate:** Not applicable.

**Consent to Publish:** The authors declare that they consent to publish this paper.

**Authors Contributions:** SK-B: Project administration, Methodology, Data curation, Investigation, Software, Writing - original draft. RY: Supervision, Project administration, Methodology, Investigation, Data curation, Software, Conceptualization, Validation, Writing - review & editing. AJ: Formal analysis, Conceptualization, Methodology, Investigation, Validation, Writing - original draft. KK: Validation, Writing - review & editing. SHE: Validation, Writing - review & editing.

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**Competing Interests:** The authors declare no competing interests.

**References**


**Figures**
Figure 1

Biogas production steps in this study
Figure 2

Preparation of cow and chicken manure

Figure 3

A) metal digester, and B) simple PVC digester.
Figure 4

PVC digester with leachate circulation
Figure 5

Schematic of leachate circulation in PVC digester
Air compressor

**Figure 7**

pH measurement of raw materials.
Figure 8

Collection of produced biogas.
Figure 9

Measuring the volume of biogas produced.
Figure 10

Gas measurement device.
Figure 11

pH changes in the biogas production process using cow manure.

Figure 12
pH changes in the biogas production process using chicken manure.

Figure 13

Volume of biogas produced daily from cow manure in digesters.
Figure 14

Volume of biogas produced daily from chicken manure in digesters.

![Bar chart showing biogas production from chicken manure in different digesters.](image)

Figure 15

Volume of biogas produced using cow and chicken manure in different digesters.
Figure 16

The amount of methane produced using cow and chicken manure in different digesters.
High costs of developing new energy sources such as biogas (Heidari-Maleni et al., 2023).

Figure 17

- Basic support costs.
- Research and development costs.
- Protection and care costs.
- Costs of economic development and technology of related industries.
- Tax deductions and other conventional expenses such as initial investment, operating expenses, management, repairs, etc.
Figure 18

Limitations and existing obstacles for the development and production of biogas in Iran (Heidari-Maleni et al., 2023).