Investigating the Fast Anaerobic Digestion of Urban Waste and the Efficiency of Biogas Production in Combination with Animal Waste (Case Study: Qazvin Urban Waste)

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Abstract

The process of anaerobic digestion and biogas production, like other biochemical reactions, is affected by various physical and chemical factors. This research was carried out with the aim of increasing the rate of biogas production, reducing the feed retention time in the digester, and increasing the amount of biogas production, by investigating the effect of co-digestion of urban solid organic waste with cow waste by anaerobic digestion method. For this purpose, 52 samples of mixed municipal waste (during the year 2021, once a week and one sample each time) were prepared from the waste transfer station of Qazvin city, And in order to investigate the effect of manure on the studied variables, 50 kg of fresh manure was collected from a cattle farm located in the region. After preparing the samples, a laboratory bioreactor was used to perform the experiments. The biogas production process was carried out in two stages. In the first stage, urban waste materials were used, and in the second stage, a combination of urban waste materials and animal manure was used. The results showed that with the use of animal manure in the initial feed and keeping other variables constant, the retention time has decreased by 6 days compared to the first stage. Also, taking into account the cumulative amount of biogas production, it was found that in stage 1 and 2, 140.89 and 230 lit.kg^{-1} VS of biogas were produced during the digestion period, respectively. Therefore, the efficiency of biogas production has increased by 38%.

Keywords: anaerobic decomposition, biogas, municipal waste, animal manure, retention time

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Introduction

Waste materials, including biological waste, are continuously being produced due to the inevitable activities of humans and animals. As of 2016, about 1300 tons of municipal solid waste was generated annually worldwide (Kumar & Samadder, 2017) and it is predicted that the rate of municipal solid waste generation will increase and reach more than 2000 tons by 2025, which is more than 40% of it will be biological (Pavi, *et.al.* 2017). Among the factors related to this increase, we can mention the increase in population, increase in urbanization rate, industrialization, economic growth and change in eating habits and consumption patterns (Khan, *et.al.* 2016). Currently, municipal solid waste creates a huge

management burden for municipalities, some of which fail to collect all the waste generated. In most developing countries, municipal solid waste aa involves collection, transportation and disposal with little or no emphasis on resource recovery.
Every year in the world, about 74 million tons of methane gas from livestock waste and 40 million tons from urban solid waste are produced by themselves and spread in the atmosphere and cause environmental pollution. It is possible to collect these waste materials and produce methane gas using biogas production devices (Sheikh Ahmadi & Zargarzadeh, 2009).
In Iran, 50 million kg of waste is produced daily, which on average contains 71% by weight of perishable materials and has energy equivalent to 575,350 barrels of crude oil per day (Adl, 2008). The annual average gas extraction from landfills is about 7 m^3 per ton of waste, which is very low compared to the theoretical efficiency of biogas production. Gas extraction in these conditions will be cost-effective for very large cities. However, by using the process of anaerobic digestion of perishable waste, the total amount of biogas that can be produced in the country (assuming 60% process efficiency) will reach 1645.7 million m^3 of biogas per year. Various methods have been used to manage and reduce the growing amount of biological waste. Burial, incineration and gasification are the three main methods that are widely used all over the world. However, such technologies lead to secondary environmental effects. Landfilling can lead to soil and underground water pollution and impose more measures and costs to remove the pollution. Also, this method requires large lands (Cheng & Hu, 2010). If this method is not managed well, it will cause air pollution and subsequent environmental and health effects. During the burning process, a number of harmful products such as dioxins, furans, heavy metals, SOx, NOx, HCl and HF are produced. Therefore, it is necessary to use a flue gas purification system in this method (Poggio & Grieco, 2010). Burning animal waste requires additional fuel due to its high moisture content and very low calorific value (Bujak, *et.al.* 2018). In addition, the net balance of positive energy resulting from combustion is obtained only if the moisture content of the biomass is less than 60%. In the pyrolysis method as well as the gasification method, the energy efficiency decreases with the increase in humidity, and the presence of water in the produced bio-oil will be a weakness. Therefore, the use of these technologies requires a drying step to reduce the moisture content of biological waste. In contrast, anaerobic digestion (AD) is a microbial process that converts biomass into energy in an aqueous environment. Biomass sources, even with less than 40% dry matter content, can be used in the AD process. Recent studies confirm a higher capacity to improve AD systems compared to the burning method (Appels, *et.al.* 2011).
Reducing climate change caused by the consumption of fossil fuels requires the use of alternative and renewable energy sources. Energy obtained from biomass is considered as an important renewable energy source in the future because it is able to produce sustainable electricity and is also an essential part of the policy to reduce CO_2 emissions (Kwietniewska & Tys, 2014). Biofuel production from biomass has received increasing attention in recent years. Several refining processes and technologies have been developed to obtain sustainable and affordable biofuels, for example SNG is a synthetic gas produced from the gasification of carbon in fuels that have some energy. However, SNG production is limited due to the high cost of this process (Guo, *et.al.* 2015).
Anaerobic digestion (AD), which is widely used for biomass purification, is considered as one of the most favorable processes for producing biofuel from biomass. AD technologies can be classified into three main classes based on total solids (TS) content: wet AD with dry matter less than 15%, dry AD with dry matter

less than 25% and solid state AD with dry matter content up to 40%. Currently, wet and dry anaerobic digestion methods are mostly used (Di Maria, *et.al.* 2017). During the AD process, organic matter is decomposed by a microbial consortium in an oxygen-free environment. The main result of the AD process is the production of methane (50-75%), carbon dioxide (19-34%) and a small fraction of biohydrogen (less than 1%) (Mathes, *et.al.* 2007). Methane obtained from AD can be used as an alternative energy source for fossil fuels. Depending on the type of waste, the energy capacity can vary from 20 to 300 Kw.hr of net energy per ton of waste (Martinez, *et.al.* 2012). The biological process of AD is based on the biochemical conversion of organic matter into methane, which occurs through the metabolic action of methanogenic bacteria and archaea (Brennan & Owende. 2010). Metabolic reactions during AD include four stages of hydrolysis, acidification, acetogenesis, and methanogenesis, which are performed by different groups of microorganisms. Complex organic compounds are first hydrolyzed to monomers such as glucose, amino acids, and long-chain fatty acids (LCFAs) through enzymatic reactions, and are subsequently converted into volatile fatty acids, H_2, and acetic acid in the acidogenic pathway. During the metabolic pathway of β-oxidation, LCFAs are degraded to H_2 in different stages. Acetogenic bacteria convert volatile fatty acids into H_2, CO_2 and acetic acid in the stage of acetogenesis. In Homoacetogenesis, hydrogen is used to reduce carbon dioxide to acetate. Finally, methanogens convert H_2, CO_2 and acetate into CH_4 and CO_2 (Khalid, *et.al.* 2011).
The process of anaerobic digestion and biogas production, like other biochemical reactions, is influenced by various physical and chemical factors. Various factors such as the nature of the substrate (nutrients for feeding enzymes), humidity, volatile solids, structure of nutrients, particle size and their biodegradability, digester design, inoculation, alkalinity, temperature, loading rate, hydraulic retention time and such cases affect the stability of the process and biogas production (Kiran, *et.al.* 2014).
The digestion of various biodegradable waste materials has proven that the potential of methane production through combined digestion experiments is higher than that of individual digestion. Most of the agricultural residues have a lot of nutrients (high nitrogen), while the lignocellulosic property makes them resistant to microbial enzyme attack. Despite this fact, in the anaerobic digestion of these types of substrates, not enough biogas is obtained. To improve the digestion of agricultural residues, they are mixed with animal manure that has a high amount of carbon to facilitate the production of biogas containing the appropriate amount of methane and to increase the flammability of biogas. For example, the combined digestion of paper waste with cow manure leads to the production of biogas with a higher quantity and quality than when they are digested separately (Ofoefule, *et.al.* 2010). The best combination ratio of agricultural residues and animal manure is one to one ratio (Vivekanandan & Kamaraj. 2011). In Table 1, for some substrates, individual and combined digestion has been compared.

Table 1 - Comparison of some substrates, individual and combined digestion and their degradability (Taheri, *et. al*, 2020)

individual digestion		combined digestion	
feed	Decomposability($m^3.kg^{-1}$ VS)	The combination with the main feed	Decomposability($m^3.kg^{-1}$ VS)
pig manure	**0.23 to 0.62**	Fish waste with biodiesel	**0.62**
cow manure	**0.2 to 0.5**	Olive pomace waste	**0.179**
Fruit and vegetable waste	**0.15 to 0.47**	Agricultural waste and energy crops	**0.62**
Municipal solid waste	-	Municipal solid waste	**0.532**
Potato residue	**0.27 to 0.39**	Fly ash	**0.222**

	Oil and grease waste from sewage treatment plant	**0.35**
	Sugar beet residue	**0.68**

In a research, anaerobic fermentation of food waste along with rare complementary elements (cobalt, iron, nickel and molybdenum) was investigated. Anaerobic fermentation of food waste alone failed, but with complementary elements, it was continuously carried out for 366 days, and the highest yield of methane (451-352 ml/g of volatile dry matter) remained during 21 to 31 days obtained (Song, *et. al,* 2012.). In a study, the combined digestion of cow manure and organic solid waste was evaluated. The results showed that in the combined state, biogas production is more and has a more stable trend (Hartmann & Ahring. 2005). In the same year, the combined digestion of food waste and aerobic sludge from industrial waste were investigated and the results showed that the combined digestion of two wastes can reduce methanogenic inhibition and methane yield (Satyanarayan & Murkute, 2008). In 2008, an experiment was conducted on biogas production using mustard flour and cow manure. The results showed that the mixture of 31% of mustard meal with cow manure will produce more biogas than either alone (Satyanarayan & Murkute, 2008).

Raw materials cannot be entered into the biogas machine in the same way, but before loading, they should be examined in terms of concentration, ability to absorb bacteria, C/N ratio, temperature, and the absence of toxic substances and inhibitory elements. According to recent technological advances, lignocellulosic conversion through pre-treatment before digestion can be used to maintain industrial balance. Pre-treatment causes no accumulation of lignocellulose in lignin, cellulose and hemi-cellulose, and more enzymatic degradation is done by bacteria, as a result, enough biogas is produced. The evidence shows that this method increases the possibility of hydrolytic enzymes by lignocelluloses and also the improvement in the pre-treatment method causes more access to cheaper feed, so biogas production will increase significantly (Scaglione, *et.al,* 2008).

In biogas production, the reaction speed is affected by temperature. In addition, temperature has an effect on the solubility of heavy metals, carbon dioxide and, as a result, on the composition of the gas. Temperature fluctuations affect microbial growth and result in a significant decrease in biogas production. The required temperature for anaerobic digestion is as follows (Safley & Westerman, 1992). Psychrophilic digestion: the retention time is more than 100 days and the reaction temperature is 10 to 20 °C; Mesophilic digestion: retention time between 30 to 60 days and reaction temperature 20 to 35 °C, thermophilic digestion: retention time between 10 to 15 days and reaction temperature 50 to 60 °C. Anaerobic reactions in biogas devices generally take place at a temperature of 10 to 60 °C. Bacteria that are active at 30 to 40 °C are known as mesophilic and those that are active at 45 to 60 °C are known as thermophilic bacteria. Thermophilic digestion improves the rate of methane gas release and its production, so it needs less retention time. Also, due to the high temperature, this type of digestion destroys pathogenic factors (Ten Brummeler, *et. al,* 1992.) and for systems with a high percentage of solids, it works better than mesophilic digestion. In addition to its advantages, this type of digestion also has problems, such as lower stability and greater sensitivity to incoming feed (Gra, *et.al,* 2008). The high temperature of this type of digestion makes the process and the digester need more control and maintenance, for this reason it is not recommended for temperatures higher than 45 °C. To improve the fermentation temperature and prevent its wastage, the building of biogas units is built according to the climatic conditions of the region.

Normally, single-stage digesters were widely used for biogas production in the past, while their use includes limitations, including the possibility of greater instability due to various factors (Kizilaslan & Onurlubas, 2010). Two-stage continuous biogas systems are used for commercial and industrial purposes, guaranteeing the continuous production of biogas and slurry. The two-stage digestion system by separating the steps of hydrolysis-acidification and methanation for anaerobic digestion of fruits and vegetables results in more stability of the process and increased biogas production. Further studies have shown that the separation of acidification and hydrolysis in anaerobic digestion can lead to a reduction in retention time along with an increase in biogas and methane gas production. A research has been done to compare these two types of digesters, which showed that the two-stage digester has a 16.5% increase in energy production compared to the one-stage digester (Kizilaslan & Onurlubas, 2010).

The yield of methane production in the anaerobic digestion processes of municipal organic solid waste alone is low. The combination of animal waste or other additives to municipal solid waste as feed for the anaerobic digestion system not only increases the percentage of methane, but also increases the rate of biogas production (Rivas-García, 2020). Carbon and nitrogen are essential elements for the growth and reproduction of aerobic microorganisms. The balanced ratio for C/N in the process is between 20-30. Simultaneous digestion is used to balance the C/N ratio (Yousefi & Bahri, 2021). This process has many advantages, including the synergistic effect of microorganisms, increasing the stability of the process, increasing the efficiency of biogas, increasing the recycling of nutrients and reducing odor.

In this research, it has been tried to evaluate the effect of co-digestion of municipal solid organic waste with cow waste by anaerobic digestion method with the aim of increasing the biogas production rate, reducing the feed retention time in the digester and increasing the biogas production rate.

Materials and methods

Demographic situation and amount of domestic waste production in Qazvin city

Qazvin urban complex is the sixth largest urban complex in Iran after Tehran, Mashhad, Tabriz, Isfahan and Shiraz. This urban complex includes the city of Qazvin and the cities, towns and urban areas around it, which has a population of about 750-800 thousand people. The area of this complex is 1423 km^2. Figure 1 shows the location of Qazvin city in Iran.

The population of Qazvin city in 2021 was equal to 621,800 people, of which 312,511 were men and 309,289 were women. The population of this city is increasing rapidly, so that the population has reached from 88,000 people in 1955 to more than 620,000 people in 2021. Each person in Qazvin city produces 800 grams of waste daily, which is double the world standard. According to the per capita waste generation by the people of Qazvin city, about 496 tons of household waste are produced in this city daily.

Municipal waste management in Qazvin is the responsibility of Qazvin Municipal Waste Management Organization. Mohammad Abad waste management site is the most important waste collection and management center in Qazvin city. This site was built in 2011 with a capacity of 2000 tons. Currently, in the processing lines of this site, the waste enters the landfill directly, while at the beginning it was supposed to separate and process the waste, but this process was not done and with the passage of time, many problems arose and now the landfill is full.

Sampling method and laboratory examination of samples

In this research, 52 samples of mixed urban waste were prepared (during the year 2021, once a week and one sample each time). All samples were taken from the waste transfer station of Qazvin city. The reason for choosing the transfer station as the sampling location was that all urban waste is transferred to this station. Also, there is a roofed area in this place that prevents the influence of climatic conditions such as rain on the samples. Sampling and preparation of samples was done according to ASTM D 92-5231 standard (Jabari *et.al.* 2016). Based on this method, all waste components were placed in a mortar after being weighed by a digital scale for 24 hours at a temperature of 105 °C. The ash content was also determined after exposure to a temperature of 770 °C for one hour (Gidarakos *et.al.* 2006). To calculate the calorific value of waste, the dry weight of each waste component was multiplied by its energy content (Kreith & Tchobanoglous, 1994).
In order to investigate the effect of animal manure on the studied variables, 50 kg of fresh manure was collected from a cattle farm located in the region and then transferred to the laboratory to examine mineral compounds and chemical variables. Table 2 shows the test result of a 1 kg sample.

Table 2- The composition of minerals and some chemical characteristics of the cow manure sample used in the research

Variable	Unit	Value
N	%	**2.32**
P	%	**0.73**
K	%	**1.97**
Organic matter	%	**82.14**
Dry matter	%	**21.12**
EC	$dS.m^{-1}$	**19.14**
PH	-	7.6

Mass and stoichiometric balance to calculate the amount of biogas production in the theoretical state
If the specific organic components in urban waste (except plastic) are considered as the general formula $C_nH_aO_b$, the total volume of produced gas assuming complete biological conversion of organic waste to $CO_2$and CH_4can be using equation 1, which is known as Bazul's equation, obtain (Shariat Hosseini*, et.al.,* 2020):

$$C_nH_aO_b + \left(n - \frac{a}{b} - \frac{b}{2}\right) H_2O \Rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) CH_4 + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right) CO_2$$

(1)
Using equation 1 and the physical and chemical specifications listed in Tables 2 and 4, the following chemical relationship was obtained:

$$C_{55.94}H_{86.98}O_{29.71} \Rightarrow C_{56}H_{87}O_{30}$$

Also, the amount of chemical oxygen demand (COD) can be calculated from equation 2:

$$C_nH_aO_bN_c + \left(n + \frac{a}{4} - \frac{b}{2} - \frac{3c}{4}\right) O_2 \Rightarrow (n)CO_2 + \left(\frac{a}{2} - \frac{3c}{2}\right) H_2O + (c)NH_3$$

(2)
These equations were used to estimate the amount of biogas production and the volume of methane gas produced in the anaerobic decomposition process in a theoretical state.

Biogas production process in laboratory conditions

Fig 2- The bioreactor used in the research

In order to evaluate the type and amount of raw materials (feed) on the variables studied in the research (increasing the rate of biogas production, reducing the retention time in the digester, or in other words, reducing the length of the anaerobic digestion period and increasing the amount of biogas production), a laboratory bioreactor located in Waste management organization of Qazvin city was used. This bioreactor is shown in Figure 2. The biogas production process was carried out in two stages. In the first stage, 12 kg of urban waste, which only contained organic matter and represented the average components of urban waste organic waste, was crushed by a grinding machine. Then the sample was placed in the digestion tank. The temperature conditions during the process were set to mesophilic mode. To create mesophilic conditions, the contents inside the tank were exposed to an average temperature of 37 °C by means of a thermal jacket with a rotating flow of hot water. In order to prevent formation of foam and surface crusts on the surface of the sludge in the reactor and also to keep the solution uniform in terms of concentration and temperature, the contents of the tank were mixed continuously through an agitator. Mixing was done through a mechanical agitator for an average of 3 days a week for 3 hours at a rotational speed of 60 rpm (Yousefi & Bahri, 2021). This process was done continuously for 38 days. During this period, the relative pressure and temperature inside the digester were measured and recorded regularly. UNIK 5000 type pressure transducer with 0.04% accuracy was produced by GE in USA. The temperature was measured through a thermocouple embedded inside the tank with an accuracy of 0.1 °C. The criterion for the end of the digestion time was the constant relative pressure inside the digester for about a week (Yousefi &

Bahri, 2021). The type of reactor feeding was batch. In order for bacteria to be able to absorb organic substances, it is necessary that the substances become soluble because water is one of the main elements for feeding microorganisms, which causes the movement of bacteria, the activity of cellular enzymes, the hydration of biopolymers, and also facilitates the breakdown of cells. For this purpose, 10 lits of water were used to dilute the mixture.

In the second stage, a feed consisting of 12 kg of shredded organic solid waste was prepared along with 3 kg of cow excrement in 10 lits of water. The temperature and rotational speed of the agitator were considered similar to the first stage. The duration of gas production lasted 32 days. All test steps were repeated according to the previous two steps.

In order to calculate the daily volume of biogas produced in the digestion process, the relationship related to the law of gases (relation 3), which is also known as the combined law of gases, was used:

$$\frac{P.V}{T} = Constant$$

(3)

Now, by generalizing the above equation for the gas inside the digester tank, equation (4) can be obtained:

$$\frac{P_2.V_2}{T_2} = \frac{P_1.V_1}{T_1}$$

(4)

Where V is the volume of gas at temperature T and pressure P. Now, to calculate the daily volume of biogas in the bioreactor, equation 4 was used with the daily measurement of temperature and gas pressure inside the tank. The normal operating temperature of the bioreactor (T_1) was considered to be 20 °C (1.293 °K) and the normal pressure of the bioreactor (P_1) was considered equal to 1 bar. The volume of bioreactor gas tank (V_1) was considered as 30 lits.

Results

Results of urban waste analysis

The composition of waste materials of Qazvin city is presented in Table 3 and the percentage of chemical components of waste materials is presented in Table 4. The data in Table 3 were used in the calculations related to the mass balance and stoichiometry of biogas production in the theoretical state, and the data in Table 4 were used to calculate the C/N.

Table 3- Composition of waste materials of Qazvin city in 2021

Composition	Components (%)	Moisture (%)	Ash (%)	Combustible materials (%)	Energy Content, $MJ.kg^{-1}$
organic waste	63.7	44.3	11.1	17	1.8
Paper and cardboard	6.4	0.51	0.45	6	2.1
Plastic	6.9	0.11	0.12	5.5	2.1
textiles	3.5	0.37	0.68	4	1.3
rubber	2.2	0.09	0.98	2.7	1.4
leather	1.3	0.1	4.1	2.1	0.9
Wood	2.4	2.4	4.8	2.7	0.6
Glass	2.1	0.07	0.9	0	0.004
Ferrous metals	1.6	0.09	2.11	0	0.008
Non-ferrous metals	1.9	0.09	1.9	0	0.07
etc	8	2.5	11.2	2	0.7

Total	**100**	**50.63**	**38.34**	**42**	**10.98**

Table 4- Percentage of chemical components of waste materials

Components	C	H	O	N	S
organic waste	39.18	1.95	37.55	2.02	9.95
Paper and cardboard	43.41	5.82	44.32	0.25	0.2
Plastic	60	7.2	22.8	0	0
textiles	46.19	6.41	41.85	2.18	0.2
rubber	77.65	10.35	0	0	2
Wood	49.7	6.1	41.85	2.18	0.2
Glass	0.52	0.07	0.36	0.03	0
Metals	4.54	0.6	4.3	0.05	0.01

Results of mass balance and stoichiometry of biogas production in theoretical mode

Since the volatile solids in Qazvin urban waste was 63.7% (Table 3) and if the amount of decomposition of organic materials is considered to be 80% and the conversion efficiency of organic materials to biogas is considered to be 83% (Shariat Hosseini*, et.al.* 2020), the results of the mass balance were obtained based on equations 1 and 2 according to Table 5:

Table 5- Results of mass balance and stoichiometry of biogas production

Parameter	Value	Unit
Methane	**55.98**	%
Carbon Dioxide	**44.01**	%
Volume of methane gas produced per 1 kg of volatile solid (VS)	**0.37**	$\frac{m^3 nCH_4}{kg\ VS}$
The amount of methane gas produced per 1 kg of decomposed volatile solids (VDS)	**0.47**	$\frac{m^3 nCH_4}{kg\ VDS}$
Volume of biogas produced per 1 kg of decomposed volatile solids (VDS)	**0.84**	$\frac{m^3 n\ biogas}{kg\ VDS}$
The volume of methane gas produced per 1 kg of volatile solid decomposed, taking into account the decomposition conversion efficiency (VBS).	**0.56**	$\frac{m^3 nCH_4}{kg\ VBS}$
The volume of biogas produced per 1 kg of decomposed volatile solids, taking into account the decomposition conversion efficiency (VBS).	**1.01**	$\frac{m^3 n\ biogas}{kg\ VBS}$
Chemical Oxygen Demand (COD)	**1.58**	$\frac{kg\ COD}{m^3.day}$

As can be seen, in the theoretical state, the amount of biogas produced, considering the conversion efficiency of 83%, is about 56%, and the volume of methane gas produced per 1 kg of volatile solid during the process is 0.37 m^3 (equivalent to 370 lits per 1 kg of volatile solid).

Composition and conversion of gaseous elements in the process of biogas production

In Table 6, the results of the decomposition of the gaseous elements that make up the primary feed and the materials resulting from its anaerobic decomposition in the biogas production process, obtained by the gas chromatography device, are presented. The value of four main elements including carbon, nitrogen, hydrogen and sulfur has been investigated. Based on the data in Table 6, the ratio of carbon to nitrogen (C/N) in the primary feed and the residual materials in the first and second stages was obtained. In this way, this ratio was estimated as 19.39 and 27.64 for the primary feed and the residual materials in the first stage and 18.60 and 28.23 respectively for the second stage. As can be seen, the conversion percentage of carbon and nitrogen has increased both in the first stage and in the second stage of the experiments, so that these values for carbon and nitrogen are 2.62% and 31.68% respectively for the stage first and it was 23.08 and 49.32 percent for the second stage. This shows that in the second stage compared to the first stage, the role of these two elements in the biogas production process has become more effective and one should expect more biogas production in the process because the increase in the conversion of organic matter and nitrogen means more effective decomposition of these materials by microorganisms that this result was achieved by adding animal manure to the primary feed.

Table 6- Gaseous elements in the feed and residual materials in the biogas production process and their conversion percentage

Test stages		Element (%)				C/N	Conversion C (%)	Conversion N (%)
		C	N	H	S			
Test stage 1	Basic food	**39.18**	**2.02**	**1.95**	**9.95**	**19.39**	**2.62**	**31.68**
	residual materials	**38.15**	**1.38**	**0.84**	**2.14**	**27.64**		
Test stage 2	Basic food	**41.11**	**2.21**	**2.08**	**8.19**	**18.60**	**23.08**	**49.32**
	residual materials	**31.62**	**1.12**	**1.79**	**1.64**	**28.23**		

The Composition of primary (Basic food) and secondary materials (residual materials) in the biogas production process

Table 7 shows the results of the laboratory analysis of primary materials (feed) and secondary materials (resulting from anaerobic decomposition) in both stages of the experiments. In this table, the changes in the amount of organic matter, dry matter, moisture and ash of the primary feed and secondary material during the process of anaerobic decomposition in the bioreactor are presented. As can be seen, the dry matter, which consists of organic matter and ash, is the main part of the degradable material in the biogas production process. Ash also consists of components that improve the activity of microorganisms, which are sometimes not decomposed and remain in the digestion process. Although in this study, the amount of ash decreased during the process, which indicated the participation of this substance in improving the activity of microorganisms. As can be seen in the table, in both stages of the experiments, the organic matter of the primary feed decreased during the digestion process, which indicates the decomposition of these substances during the process. Also, the conversion percentage of dry material from primary feed to secondary material in stage 1 and 2 was 8.2% and 10.5%, respectively, which shows that in the second stage, in which the combination of animal manure was used, the percentage of conversion the dry matter is more and the process has progressed towards the production of biogas.

Table 7- Composition of primary feed and secondary materials in anaerobic digestion process

Test stages		Variable (%)			
		Organic Matter	Dry Matter	Moisture	Ash
Test stage 1	Basic food	**44.60**	**55.70**	**44.30**	**11.10**
	residual materials	**42.00**	**51.10**	**48.90**	**9.10**
Test stage 2	Basic food	**49.30**	**55.70**	**44.30**	**6.40**
	residual materials	**45.30**	**49.80**	**50.20**	**4.60**

The rate of changes in pressure and volume of biogas in the digester tank during the digestion process

Figures 3 and 4 respectively show the changes in pressure and volume of biogas per unit mass of feed in the digester tank during the decomposition process and at each test stage. As mentioned earlier, the digestion process in the bioreactor lasted 38 and 32 days in the first and second stages, respectively. Therefore, during this period, the trend of changes in relative pressure inside the biogas tank was measured and recorded daily by a pressure transducer so that the diagram of changes in relative gas pressure could be drawn.

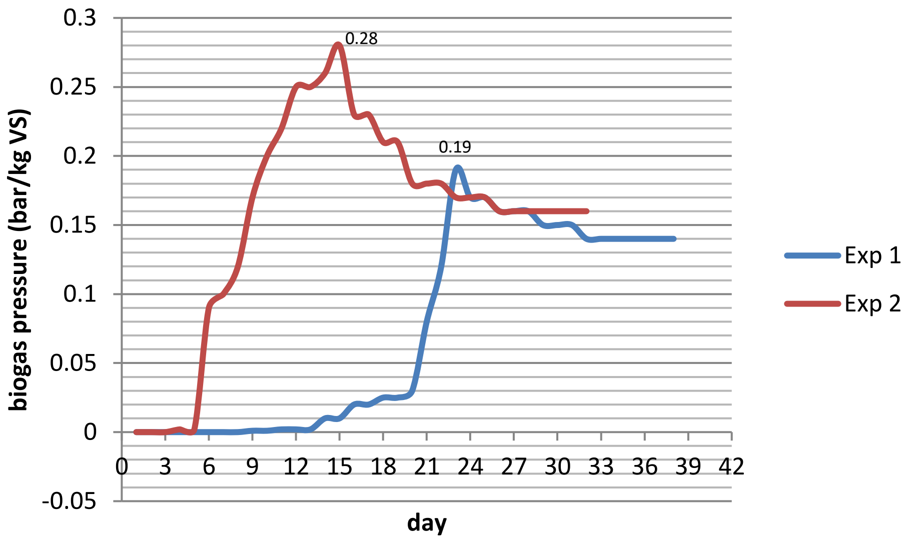

Fig 3- Biogas pressure changes per unit of feed mass in the digester tank during the decomposition process

According to the diagram in Figure 3, the changes in the pressure of biogas inside the tank in the experiment related to stage 1 reached its maximum value (0.19 bar/kg VS) within 23 days after the start of the process, and then in the last 7 days at the value of 0.14 bar/kg VS, is fixed. Since the criterion for the completion of the digestion process was pressure stabilization in 7 consecutive days, therefore, after 38 days, the first stage process was completed and the biogas and residual (secondary) materials were discharged. The maximum biogas pressure in the second stage test was 0.28 bar/kg VS, which was achieved on the 15th day, and finally, after 26 days, the pressure reached 0.16 and stabilized at this pressure for 7 days. Therefore, the digestion process in the second stage lasted for 32 days. Therefore, it can be seen that by using animal manure in the primary feed and keeping other variables constant, the retention time has been reduced by 6 days compared to the first stage.

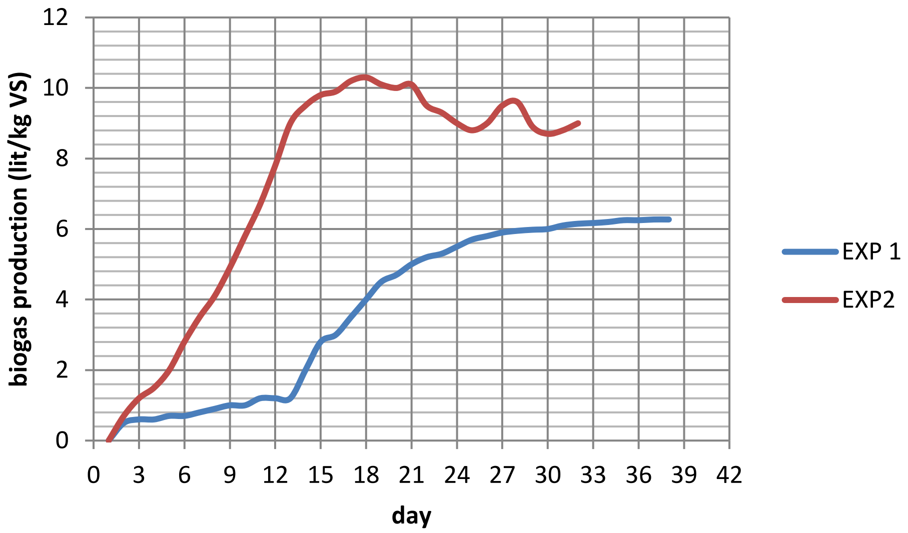

Fig 4- Biogas volume changes per unit of feed mass in the digester tank during the decomposition process

As can be seen in the diagram of Figure 4, the daily amounts of biogas production were calculated based on equation 4 and drawn for both stages (Exp1 and Exp2). The maximum amount of biogas produced in stage 1 was equal to 6.27 lit/kg VS and in stage 2 it was equal to 10.3 lit/kg VS. As can be seen, by using animal manure in combination with urban organic waste, the volume of biogas production has increased under the same conditions. Taking into account the cumulative amount of biogas production, it was found that in stage 1 and 2, 140.89 and 230 lit/kg VS were produced during the digestion period, respectively. Therefore, the efficiency of biogas production has increased by 38%. Although the total amount of biogas produced in both stages of the experiments compared to the theoretical values obtained in this study (at the rate of 370 liters/kg of solid matter) and also reported by other researchers (Salehoun, *et.al,* 2020 and Kozminesky, 1995) has been less.

Conclusion

According to the results of this study, it was found that in the second stage, compared to the first stage, the role of two elements, carbon and nitrogen, became more effective in the biogas production process, and one should expect more biogas production in the process. Because the increase in the conversion of organic matter and nitrogen means more effective decomposition of these substances by microorganisms, which was achieved by adding animal manure to the primary feed. According to the results obtained from this study, it can be concluded that in the process of biogas production, the combination of animal manure with urban organic waste, in addition to reducing the retention time, can help to increase the efficiency of biogas production, which in this study a 38% increase in biogas production was observed in the case of using a combination of animal manure with urban organic waste compared to using only urban organic waste. Although the role of other variables such as temperature, type and amount of agitator, type of initial preparation of materials in terms of size, humidity, pH, addition of yeast and bacteria, degree of impurity and toxicity of materials, C/N, type and size of reactor and other examined the variables can be investigated.

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