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The optimal mixing ratio of cow manure with food waste using a laboratory up flow anaerobic sludge blanket reactor

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ABSTRACT

The upper flow anaerobic sludge blanket (UASB) reactor is an important anaerobic treatment method for treating organic waste in various forms. Biogas production in Syria is still in its primitive stage and has become an urgent necessity, coupled with the presence of a significant amount of primary biomass, estimated at 379 million tons annually, which can generate approximately 4.6 billion cubic meters of biogas when processed. A laboratory-scale UASB reactor with a diameter of 19 cm and a height of 115 cm was designed to maximize methane gas production. The mixing ratios of cow dung with food waste used were 20%, 30%, and 40% at a temperature of 35 °C for a duration of 35 days. Several parameters that affect gas production were measured. The methane gas production was 7.4 L at 20% food waste, 7.1 L at 40% food waste, and 6.6 L at 60% food waste. The highest biogas yield was achieved with 20% of food waste and cow dung due to its proximity to the ideal carbon to nitrogen (C/N) ratio.

Keywords: upper flow anaerobic sludge blanket, biogas, animal dung, anaerobic treatment, solid organic waste.

INTODUCTION

The anaerobic digester is a widely applied and specialized technology in the treatment of various organic wastes and the production of biogas and organic fertilizer (Tufaner and Avsar, 2016). While there is no proper management of municipal solid waste (MSW), organic fractions can cause many environmental problems, including soil and groundwater pollution due to leaching and uncontrolled methane emissions.

Over the years, an awareness of these problems has arisen among researchers and research has led to the discovery of new technologies for renewable energy, including biogas. Therefore Rosas-Mendoza et al. (2018) emphasized the importance of improving anaerobic digestion (AD) more than ever given sustainable development and a deep understanding of biological processes for true biogas production.

Anaerobic digestion is defined as the fermentation of animal and human organic waste, plant remains, some industrial waste, and urban waste under the influence of specialized types of microorganisms known as anaerobic bacteria. It is achieved through successive and overlapping biological processes isolated from the air, which is known as anaerobic fermentation, in special devices, sealed and thermally insulated under specific conditions, and equipped with devices to stir the fermented material (Maringa, 2008).

Several experiments have addressed co-digestion anaerobic systems at different hydraulic retention periods and their effect on biogas production. Ratanatamskul et al. (2014) designed a single-stage co-digestion anaerobic prototype for kitchen waste with sewage sludge. The system was operated with hydraulic retention periods of (27-22-19) days. The biogas production rate was 1045 ± 52.81, 1386.85 ± 25.32, and 1662.58 ± 37.32 L/day, respectively. It was found that the longer the HRT, the lower the biogas production, while the methane production was higher in the biogas formulation with increasing HRT. This is because the longer the HRT improves the activity of methanogens to their final level, while the shorter HRT causes a decrease in the pH of the reactor and thus increases the acidity of the medium, which negatively affects the activity of methanogens.

Sillero et al. (2022) compared methane productivity when digesting sludge or co-digesting sewage sludge with wine vinasse or triple digestion of sludge with wine vinasse and poultry manure in gradually decreasing hydraulic retention periods. In the sludge digestion reactor alone, the reactor provided the lowest performance in methane productivity at HRT = 20 days and increased with decreasing duration until it reached a value of 130 mlCH_4/gVS added at HRT = 10 days and then decreased. For the RSV reactor, it recorded increased methane values with decreasing HRT, reaching a maximum value of 210 mlCH_4/gVS added at HRT = 13 days and then decreased methane values at a lower HRT. The RSVPM reactor followed the same path, increasing its performance with decreasing operating duration until it reached a maximum at HRT = 13 and reached 261 mLCH_4/gVS added. It was observed that with increasing OLR and decreasing HRT, daily biogas production increases until it reaches HRT at 13 days, after which it decreases. Dareioti et al., (2022) showed The effect of HRT is related to the pH of the medium, which is also related to the type of digested substrate, including the accumulation of VFA and TAN. The effect of HRT on biogas composition was demonstrated when he studied the anaerobic co-digestion of sorghum with liquid cow manure in a two-stage system (acidification stage - methanogenesis stage), where tests indicated that at HRT = 5 days and pH = 5, it gave the highest hydrogen production rate of 0.13 L/LR d and a hydrogen yield of 1.68 mol H_2/mol carbohydrates consumed. As for the methanogenesis stage, it achieved the highest productivity at HRT = 25 days and reached 295.3 mL CH_4/g VS added.

Kumari et al. (2018) confirmed that anaerobic co-digestion has a greater impact on biogas production by mixing different types of waste. In this study, sewage sludge (SS) and cow manure (CM) were used as primary wastes. Kitchen waste (KW), yard waste (YW), floral waste (FW), and dairy wastewater (DWW) are common substrates for anaerobic digestion. The mixtures were fed in a ratio of 1:2 in one stage of the upper flow anaerobic sludge blanket (UASB) reactor. The digestion process was carried out in an intermediate temperature range for 20 days. The pH and VFA were measured and ranged from 5 to 7.5 and 3500 to 500 mg/L, respectively, for all mixtures throughout the digestion period. The percentage of COD removal efficiency after 20 days ranged between 76% and 86%. It was found that the maximum biogas production rate is 4500 ml/day.

Anaerobic digestion is an important technology that plays an important role in the decarburization economy. This feature makes it a suitable partner to approach the circular economy model. As a result of the decrease in biogas production from traditional substrates,

González et al. (2022a) mentioned the common substrates used in anaerobic digestion, including animal manure (pig manure, poultry manure, cats) with high nitrogen content that may inhibit methanogens, and sewage sludge from sewage treatment plants as primary or secondary sludge that requires pre-treatment before digestion to improve its decomposition. He also mentioned food industry waste with low nitrogen content and restaurant waste rich in carbohydrates that can affect the pH of the medium and the organic part of municipal solid waste, which is criticised for its seasonality on the one hand and the presence of heavy metals on the other.

González et al. (2022a) also discussed the characteristics of crop residues and lignocellulosic biomass waste such as corn residues, wheat straw, rice straw, and agro-industrial wastes that require a long time for digestion. Due to the different properties of these individual substrates, co-digestion is an obvious solution to balance nutrients and reduce the disadvantages associated with mono-digestion. Therefore, he encouraged the use of co-substrates such as sewage sludge and animal manure, sewage sludge with municipal solid waste, slaughterhouse waste, food industry waste, or sewage sludge with food waste and garden waste. He focused on the use of carbohydrate-rich substrates, such as cheese whey and molasses, and lignocellulosic substrates, such as corn straw, that contribute to the C/N balance. He demonstrated the benefits of using cellulose pulp. He also encouraged the digestion of protein-rich substrates such as animal carcasses, glycerol from biodiesel production, grease trap waste, and the use of Microalgae biomass such as *Chlorella* sp. and *Nannochloropsis oculata*.

For geographical context, Syria enjoys a Mediterranean climate and multiple sources of energy (sun, wind, oil, water, etc.). This is in addition to the possibility of producing biogas because it is an agricultural country that contains a livestock that produces 44 million tons of natural manure per year. In terms of the economic feasibility of biomass energy in Syria, based on information from the National Energy Research Centre, the annual quantities of the main mass (manure, kitchen waste, agricultural waste, sewage water, etc.) are approximately 379 million tons. If treated with anaerobic digestion, it can produce 4.6 billion cubic metres of biogas per year, equivalent to the annual production of 27.6 million megawatt hours (MWh) of electricity and the equivalent of 2.7 billion litters of diesel, in addition to the production of 341 million tons of high quality organic fertiliser (Jafer and Awad, 2021).

Specifically, UASB reactor, is an anaerobic digester in which the liquid and the substrate flow upward through an anaerobic sludge bed was developed by Lettinga et al. in the late 1970s (Farghaly and Tawfik, 2017). It is used primarily to treat high-concentration industrial and municipal wastewater and plays a vital role in the anaerobic digestion of organic particulate matter from municipal waste (OFMSW) compared to aerobic (Singh et al., 2013).

Anaerobic treatment systems technologies such as UASB have many advantages: including simple design, uncomplicated construction and maintenance, small land requirements, low construction and operating cost, low excess sludge production, durability for COD removal efficiencies, and the ability to withstand fluctuations in temperature, pH and concentration effects, rapid recovery of biomass after decommissioning, and generation of energy in the form of biogas or hydrogen (Rizvi et al., 2017; Elmitwalli et al., 2002; Singh et al., 2013; Haandel and Lettinga, 1995; Singh et al., 2013. These properties make UASB a popular wastewater treatment option (Chong et al., 2012; Alvarez et al., 2006).

Surendra et al., (2014) highlighted the challenges and potentials of biogas production to access more research in the field of biogas to develop and spread this concept in developing countries to be used as an alternative energy source.

To evaluate the environmental and economic sustainability of anaerobic digestion systems, biogas is produced with high efficiency, with automatic treatment monitoring based on the best previous laboratory and experimental studies (Rosas-Mendoza et al., 2018).

This study aims first to find an effective solution to the problem of the increasing amount of organic waste, both domestic and animal, in the Syrian Arab Republic due to the agricultural sector in Syria, which occupies an important place in the economic sectors that are wasted without benefiting from it. second, it aims to improve the biogas production process. from anaerobic reactors in a manner that suits local conditions by conducting many experiments or laboratory models, mixing ratios, and measuring the factors affecting them to reach the largest amount of methane gas.

Stazi et al. (2022) applied a laboratory sequential overflow sludge blanket reactor to treat synthetic wastewater at 15, 25 and 35 °C and with different hydraulic retention times (gradually decreasing from 22 hours to 9 hours). The results at 25 and 35 °C showed similar efficiencies for COD removal and biogas production in the range of 84–94% and 0.14–0.27 m^3/kg COD removed, respectively. While at 15 °C the COD removal efficiency decreased and the hydraulic retention time had to be reduced to 14 hours to bring the wastewater limits to Italian standards. High quality was achieved for the TSS concentration at all temperatures. Anaerobic digestion was found to be unable to remove nitrogen and phosphorus. It was found that the percentage of methane dissolved in the waste was higher with the lower temperature because of the increased solubility of gases in liquids with the decrease in temperature. Thus, at 25 °C, more methane dissolves in the liquid waste and thus a greater loss of methane than at 35 °C.

Ngwenya et al. (2022) also reviewed most of the research on the UASB bioreactor to manage the accumulation of winery wastewater (WWW). Accelerated anaerobic wastewater treatment systems, such as the UASB bioreactor, have been shown to have the potential to save kilowatt-hours of electricity (kWh-e), water, sludge waste, and chemical residues generated during wastewater treatment. The successful implementation of the UASB bioreactor in wineries and wastewater treatment plants (WWTP) depends on the readiness of the biotechnology to manage the fluctuating discharge of raw wastewater and meet high product quality at a low cost. The conditions for optimal biogas production and removal of COD were also reviewed in the UASB bioreactor. Optimal COD removal and biogas production were observed for reactors operating under mesothermal bioreactors (30–35 °C) when OLR and HRT were 6 kg/m^3/day and 22 h, respectively, while semi-mesothermal bioreactors (19–21 °C) required OLR and HRT of 7 kg/m^3/day and 16 h, respectively.

Sintos et al. (2024) studied the long-term operation of an integrated treatment process consisting of a UASB reactor coupled to a two-stage (saturated and unsaturated) vertical subsurface flow constructed wetland (VSSF-CW) for treating domestic wastewater. The two-stage CW treated the UASB water to increase the total solids, and increased the efficiency of removing the chemical oxygen demand and oxidising the ammonium to nitrate. The UASB reactor was able to remove 50% ± 17% to 83% ± 9% of suspended solids and 43% ± 18% to 76% ± 3% of the chemical oxygen demand, resulting in the production of 0.36 N m^3 of methane/kg of biogas, which varied significantly with seasons. The two-stage continuous CW process contributed to more pollutant removal, achieving total suspended solids removal ranging from 97% ± 3% to 99% ± 0% and COD from 91% ± 2% to 96% ± 1%. The removal of incoming ammonium nitrogen ranged from 87% ± 4% to 99% ± 0% by nitrification. This solution is very promising for energy production.

MATERIALS AND METHOD

The main raw materials used to produce biogas

The waste that can be used in biogas production comes from various sources, such as animal manure, poultry waste, and human waste. To obtain the highest production of biogas, it is necessary to maintain the maximum activity of the bacteria participating in the anaerobic digestion process by providing the nutrients necessary for their growth, such as carbon, nitrogen, and phosphorus, and their optimal ratios (150 carbon: 5 nitrogen: 1 phosphorus). Table 1 shows the quantity and content of the nutritional elements required by some animal waste for the anaerobic digestion process (Engineers, 1971).

Raw material description:

Cow slurry is a homogeneous manure that contains a carbon/nitrogen ratio close to the optimum value 16–25, as stated by most of the literature (Odejobi, 2021; Haandel and Lettinga, 1995). It is commonly used as a raw material for anaerobic digestion, and its composition includes the following Table 2. The application of straw in feeding yards results in different total solids results. Cows are known to suffer from grazing for a long period of time, especially traditional cows. Cow manure contains a rich cellulose component that can be easily digested in the absence of oxygen. It is a good source of fertilizer, without any harmful effect on plants (Lamb, 2020).

Feedstock characterization

In order to use the organic fraction of OFMSW municipal solid waste as a feedstock for energy recovery (Kigozi et al. 2014), it had to undergo various selected tests to obtain the basic parameters; a final analysis of component, density, volatile solids (VSS) content, moisture content and total solids (TS) content was performed. The samples to be used were mechanically mixed and reduced to small sizes. The sample was wrapped in airtight plastic bags and kept in the refrigerator for testing. Before each test run the samples are ground using a mixer to achieve homogeneity (Table 3).

Up flow anaerobic sludge blanket reactor design

Based on the design criteria for UASB reactors that (Pererva et al., 2020) put forward, we designed the reactor with dimensions as shown in the following Table 4.

Figure 1a shows the designed USAB reactor, and the volume of gas generated was measured through a vessel based on the water displacement principle Figure 1b and then the biogas is filtered through special filters to get rid of hydrogen

Table 1. The amount of waste produced and its composition for some animals (Engineers, 1971)

Animal	Live weight of the animal 1000 pound		Live weight of the animal 500 kg		Volatile fatty acid	Nitrogen	Phosphorus
	Size foot	Wet weight pound	Size m³	Wet weight, kg	Percentage of wet weight	Percentage of wet weight	Percentage of wet weight
Dairy cows	1.33	76.9	0.038	38.5	7.98	0.38	0.1
Meat cows	1.33	83.3	0.038	41.7	9.33	0.7	0.2

Table 2. The content of fresh cow offal is one of the basic elements

Basic elements	Water	Organic matter	Total nitrogen	Nitrogen ammonia	P_2O_5	K_2O	CaO	MgO
%	75	21	0.5	0.25	0.25	0.6	0.35	0.15

Table 3. Feedstock characteristics

Parameter	Reference values (Kigozi, et al. 2014)	Actual values
Average daily generation rate	231.22 kg/day	30 kg/m^3
Total solids (TS)	27.14%	4.46%
Moisture content (MC)	72.86%	90.68%
Volatile solids (VS) (% of TS)	94.90%	3.11%
Fixed solids (FS) (% of TS)	5.1%	-
Density	775.0 kg/m^3	-
C:N ratio	25:1	4.92:0.135

Table 4. The dimensions of UASB reactor

The diameter of the sampling ports	The number of sampling ports	Total height	Inner diameter	Reactor capacity	Reactor material	Reactor type
1.5 cm	8 cm	115 cm	19 cm	32.5 L	Iron	UASB
	Vertical speed	Substrate	Stirring	Total runtime	Feeding method	Operating temperature
	0.5 –1 m/h	Cow dung with food waste in different mixing ratios	Every half hour the pump runs 2 minutes	20–40 day	Once	31.28±5 °C

sulphide gas and moisture to be collected in special balloons for toxic gases.

After the straw was removed from the cows, the dung was mixed with the food waste collected during the week in different proportions. First: Mixing ratio of dung with 18% food waste for a period of 34 days. We placed 2.2 kg of food waste and 12 kg of cow dung, and 12 litres of water were added to the mixture, mixed well, and placed in the model for 34 days at a temperature of 31 °C with an electric heater. The fermentation temperature set at 31 °C may be due to several factors. Ideal operating temperatures for anaerobic digestion range between 30 °C and 38 °C (mesophilic), where methanotrophic microbes (methanogens) are more active. Hence, digestion systems are more stable and microbial species are more tolerant to environmental fluctuations. However, we preferred this to avoid temperature changes between the experiments studied in the manuscript,

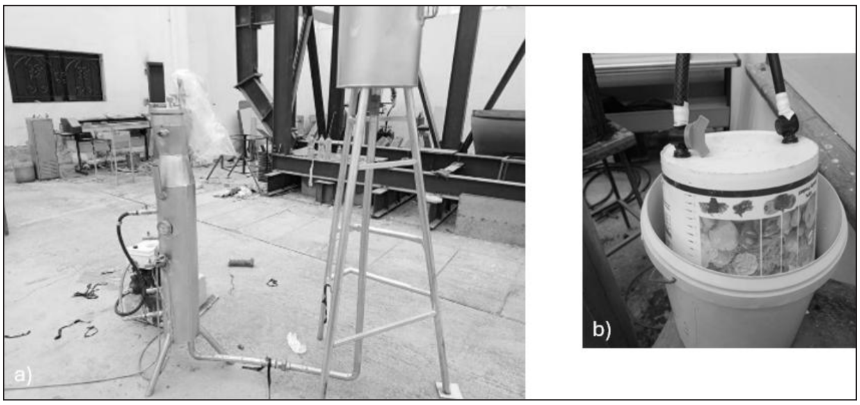

Figure 1. (a) UASB reactor (b) gas collection vessel based on the displacement principle

to take into account the change of seasons so that the laboratory conditions studied are compatible with the prevailing climate in Syria within the lowest economic costs required to raise the temperature of the reactor if applied in reality.

Second, a mixing ratio of dung with 40% food waste for a period of 34 days. We put 4.8 kg of food waste and 12 kg of cowdung and 12 litters of water were added to the mixture, mixed well, and placed in the model for 34 days at a temperature of 31 °C using an electric heater.

Third, mixing ratio of dung with 60% food waste for a period of 34 days. We put 7.2 kg of food waste and 12 kg of cow dung, and 12 litters of water were added to the mixture, mixed well, and placed in the model for 34 days at a temperature of 31 °C by means of an electric heater. The mixing ratios of food waste and cow manure are shown in Table 5.

The following Table 6 shows the characteristics of animal waste in terms of its biodegradability, biogas production rates (Aye, 2005; Obileke et al., 2017), operational characteristics and standards of animal slurry selected for biogas production (Table 7).

RESULTS AND DISCUSSION

Food waste was mixed at a rate of 20% with cow dung at a rate of 80%, and then added water at a ratio of 1:1 to cow dung and water to food waste at a ratio of 1.5: 1, The weight of the added water was 12 kg and the fermented material was stirred by a pump connected to the UASB reactor that recirculated the liquid every half hour, and the pH values decreased in the first days from 6.26 to values close to 5, then increased again at the end of fermentation to 8.6, due to the initial decomposition of food waste. While the COD values decreased from 17394 to 13720 mg/L. Biogas was characterized by higher levels of carbon dioxide and other gases compared to methane during the first days of fermentation. As fermentation continued after the first week, these concentrations gradually decreased, in contrast to the increase of methane. The peak volume of biogas was estimated at 7.4 L on day 8, with the H2S concentration being zero due to gas filtration before sample collection. When a qualitative analysis of the composition of the biogas produced for a gas balloon with a total volume of 3.5 L on day 10 of fermentation was performed, the methane content was 47.19%, the carbon dioxide content was 23.6%, the hydrogen content was 23.6%, the carbon monoxide content was 3.92%, and the O_2 content was 1.70% for the measured gas sample. Many references have shown the importance of co-digestion of cow manure with food waste to enhance methane production, as the addition of CM increases the C/N ratio (El-Mashad and Zhang, 2010; Zhang et al., 2013). This was confirmed by (Xing, 2020) who used seven different ratios of FW/CM, which are (3.4-2.5-1.7-0.8-0.4-0.3-0.2(respectively, and determined the S/I ratio = 0.05 and the pH value = 7.83, and by comparing the methane yields, it was noted that the FW/CM ratio = 2.5 gave the highest value of

Table 5. The mixing ratios of food waste and cow manure

Raw material weight	Mixing ratios%	Substrate
2.2 kg food waste	82% cow dung & 18% food waste & water	cow dung & food waste & water
12 kg cow dung		
4.8 kg food waste	60% cow dung & 40% food waste & water	cow dung & food waste & water
6 kg cow dung		
6 kg cow dung	40% cow dung & 60% food waste & water	cow dung & food waste & water
4.8 kg food waste		

Table 6. Raw material characteristics: animal waste (Obileke et al., 2017)

Waste type	C/N ratio	Water [%]	kg VS/animal unit/d
Cow dung	16–25	78–80	4.2
Horse manure	25	75	
Pig manure	14	82	2.7
Poultry waste	9.3	65	5.9

Table 7. Characteristics and operational parameters of selected animal slurries for biogas production (Obileke et al., 2017)

Slurry	TS [%]	VS [% of TS]	C/N	Biogas yield [m^3kg^{-1} VS]	Retention time
Pig	3–8	70–80	3–10	0.25–0.50	20–40
Cow	5–12	75–85	6–20	0.20–0.30	55–75
Poultry	10–30	70–80	3–10	0.35–0.60	> 30

methane production which was 646.6 mL CH_4/g. Food waste was mixed at 40% with cow dung at 60%, and water was added at 1:1 to cow dung and water to food waste at 1.5:1. The weight of added water was 13.2 kg, and the pH values were within the range of (6.85–8.6). While the reactor temperature was maintained at 31 °C, the COD values gradually decreased due to the decomposition of organic matter from 17064–16078 mg/L.

Gas production started on the sixth day and was initially non-flammable due to the low methane values and the gas volume gradually increased until it reached the highest value of 7.1 L on the ninth day and stabilized at the peak state and then started to gradually decrease again until the twenty-fifth day. The gas composition was lower in methane than in the first experiment and increased in CO_2, CO.

Because the carbon-to-nitrogen ratio of food waste (vegetables and fruits) is within the range of 35–47 while the carbon-to-nitrogen ratio of cow dung is in the range of 16–25 (Singh, 2013; Sunny, 2018) the anaerobic co-digestion process is very effective, as it addresses nutrient deficiencies (Sayra, 2019).

Odejobi, (2021) estimated the amount of methane gas produced when mixing cow dung and cafeteria waste at a 50:50 mixing ratio to be 0.460 m^3/kg TVS ADD. It is important to highlight the significant differences in the composition of food waste (Soha, 2017). In our research, we focused specifically on food waste consisting of fruits and vegetables only

Food waste was mixed at a ratio of 60% with cow manure at 40%. Water was added at a ratio of 1:1 for the manure and at 1.5:1 for the food waste, resulting in a total added water weight of 19 kg. Gas production began on the sixth day, with the gas being non-flammable. The volume of gas gradually increased, reaching a maximum value of 6.6 m^3 on the ninth day, stabilizing at that peak before gradually decreasing until the twenty-third day. The study conducted by Petracchini et al. (2017) on two-stage co-digestion indicated that when mixing food waste (52%), cow dung (26%), chopped green waste (12%), and anaerobic inoculum (10%), the pH values ranged from 75.7. The resulting gas composition was characterized by a CO_2 concentration in the range of 60–80%, which gradually decreased as methane increased from 0% on day 1 to 20% on day 7, while the hydrogen concentration rose from 0.1% to 5.5%. The amount of methane generated in the second stage was estimated to be between 0.68–0.92 N m^3/kg TVS added. The following Table 8 shows the daily biogas production rate from anaerobic fermentation with different substrate mixing ratios. Table 9 shows the statistical description of daily biogas measurements for each mixing ratio separately.

At a mixing ratio of 20% food waste and 80% cow manure, the largest amount of biogas was produced. It was noted that as the percentage of food waste increased, the rate of methane gas production decreased. In each of the three experiments, the residence time of the fermented material was maintained for up to 30 days. While (Xing, 2020) found that increasing the proportion of food waste to cow manure increased the efficiency of co-digestion and the efficiency of the hydration, acidification and methane formation processes. The reason for the difference is that he used Chinese kitchen waste that has a different composition from the waste we use (fruits and vegetables). He also adjusted the pH values and added to the fermented material an inoculum taken from the UASB reactor for treating wastewater from breweries.

We tried to find the optimal mixing ratio of food waste with cow manure, so we adopted the UASB reactor type with a single-stage feeding system and a temperature of 31 to 34 days, while (Kumari et al., 2018) adopted the use of multiple and diverse common substrates, represented by sewage sludge and cow manure as primary wastes, in addition to kitchen waste, garden waste, flower waste and dairy wastewater, with a mixing ratio of 2:1 and a temperature of 20 °C, and a single feeding system was used. Our experiment

Table 8. Daily gas production from domestic organic wastes and Cow dung. (mean value ± SD)

Day	Rate of biogas for mixing ratio (20% food waste)L	Rate of biogas for mixing ratio (40% food waste)L	Rate of biogas for mixing ratio (60% food waste)L
1	0.6 ± 0.01	0.2 ± 0	0.21 ± 0
2	1.23 ± 0	0.5 ± 0	0.89 ± 0.01
3	2.47 ± 0.01	0.78 ± 0	1.25 ± 0.03
4	3.08 ± 0	2.2 ± 0	1.9 ± 0
5	4.32 ± 0.01	3.5 ± 0.04	3.06 ± 0.1
6	6.15 ± 0.03	4.9 ± 0.01	3.31 ± 0.02
7	6.15 ± 0.02	6.1 ± 0.01	5.8 ± 0.18
8	7.44 ± 0.12	7.03 ± 0.05	6.35 ± 0.08
9	6.65 ± 1.17	7.09 ± 0.03	6.39 ± 0.31
10	6.02 ± 0.01	5.99 ± 0.03	5.62 ± 0.44
11	5.91 ± 0.07	5.7 ± 0.01	5.53 ± 0.02
12	4.97 ± 0.14	4.93 ± 0.06	5 ± 0.01
13	4.98 ± 0.03	4.39 ± 0.02	4.5 ± 0.01
14	4.2 ± 0.01	3.97 ± 0.02	4.2 ± 0.01
15	4.02 ± 0.06	3.9 ± 0.01	3.99 ± 0.01
16	3.9 ± 0.06	3.51 ± 0.01	3.71 ± 0.01
17	3.5 ± 0.01	3.4 ± 0.01	3.21 ± 0.01
18	3.2 ± 0.01	2.97 ± 0.05	3.07 ± 0.05
19	2.81 ± 0.01	2.67 ± 0	2.74 ± 0.12
20	2.5 ± 0.01	2.43 ± 0.02	2.38 ± 0.1
21	2.06 ± 0.1	1.8 ± 0.01	1.97 ± 0.11
22	1.51 ± 0.01	0.98 ± 0.02	1.55 ± 0.21
23	1.09 ± 0.15	0.6 ± 0	0.89 ± 0.65
24	0.81 ± 0.01	0.4 ± 0	0.67 ± 0.5
25	0.5 ± 0	0 ± 0	0.45 ± 0.37

Table 9. Statistical description of the different mixing ratios for daily measurements for each mixing ratio

Daily gas production from domestic organic wastes and cow dung	Count	Mean	Std	Min	25%	50%	75%	Max
Rate of biogas for mixing ratio (20% food waste)L	25	3.63	2.12	0.5	2	3.5	5	7.4
Rate of biogas for mixing ratio (40% food waste)L	25	3.2	2.2	0	1	3.4	4.9	7.1
Rate of biogas for mixing ratio (60% food waste)L	25	3.08	2.09	0	1.3	3.1	4.5	6.6

was characterized by the use of the UASB reactor only for solid waste with cow manure, while most of the reference studies adopted sewage sludge as the main substrate in the operation of UASB.

Otun (2016) demonstrated in his study the superiority of co-digestion over single digestion by using six anaerobic digesters with different loads. The first three digesters were used for single digestion, each containing either 10 kg of food waste, 10 kg of cow dung, or 10 kg of fruit waste. The Table 10 outlines the substrates used in co-digestion, their mixing ratios, and the water-to-substrate ratios for each mixture.

The results showed that the highest biogas production occurred during the co-digestion of food waste and cow dung, with an increase of 164.8%. Biogas production from the other digesters was as follows: Combined digestion of food waste, fruit waste, and cow dung: 91.0%. Combined digestion of fruit waste and cow dung: 83.9%. Individual digestion of cow dung: 79.8%. Individual digestion of fruit waste: 76.4%. Individual digestion of food waste: 77.4%.The percentages cited in the study regarding biogas production under similar conditions make it evident that co-digestion significantly enhances biogas production compared

Table 10. Shows the mentioned ratios of anaerobically digested substrates and additive water (Autton, 2016)

Waste used	Weight of waste, kg	Liters of water used, L
Cow dung	10	10
Fruit waste	10	10
Food waste	10	10
Co-digestion		
Cow dung and food waste	5 kg each	10
Cow dung and fruit waste	5 kg each	10
Cow dung, fruit and food waste	3.3 kg each	10

to single digestion. González et al. (2022a) distinguished themselves from us by studying common substrates adding natural zeolite to them as a contributing factor to increasing biogas yield, and studied the effect of ammonia and VFA on biogas yield, while our study was limited only to the substrates with different mixing ratios, without any additives, and in one stage, without having to follow the steps taken by González.

Hussien (2021) used anaerobic co-digestion of food waste from kitchens with a mixture of used cooking oils with several percentages of cow dung from the total mass of food waste with oils, which are 4, 8, 12, 16, 20% respectively. The fermentation process continued for 25 days, and the maximum and cumulative biogas production was 91.6 ml/day and 2914 ml respectively for the sample containing the highest percentage of dung 20%, and the concentration of methane in the biogas was in the range of 57–63%, and the daily methane production values ranged.

The values of parameters affecting biogas production

The pH values ranged between 6.5 to 7.4, and the solid matter concentration was 10–15%, so that the moisture ranges from 85 to 90%, and the COD value ranged between 15–19 g/L and the percentage C/N = 9.9, at a temperature of 31 °C, and the following Table 11 shows the average measured parameter values for the selected substrates.

This table shows the values of the parameters affecting the production of biogas, so that the pH values are the optimal values for the reproduction and activity of methanogenic bacteria we find that the ratio of carbon to nitrogen is lower than the optimal value determined by many references, which is 25–30. Also, we find that the concentration of the substance Solid does not exceed 10%, so that most Moisture values range between 88% and 90%.

By comparing the results of Table 8, the case study, with Table 12, in which Kumari explained the parameter values for the multiple substrates that he used. The variable pH values depending on the type of substrate are within the range of 4–8, while our value was between 7–6.5. Kumari et al. (2018) discussed in his study the value of total carbon and accumulation of fatty acids (VFA), in contrast to us, we focused on the ratio of carbon to nitrogen because it is one of the most important factors influencing the production of biogas, despite its low value in our research, and this is due to its calculation of the substrate after adding water.

González et al. (2022b) refrained from mentioning any of these parameters, contenting himself only with a comparison between biogas production rates for different substrates, especially after adding natural zeolite. Petracchini et al. (2017) studied the substrate properties related to total solids, proteins, and peptides, and the COD removal efficiency, which ranged between 15,000–25,000 mg/l, and the pH between 5.5 and 7.

We find that we are similar to using a common substrate up-flow anaerobic sludge blanket reactor and that the biogas production process lasted for 20 days, and also, the optimal amount of gas production was approximately the maximum biogas production rate of 4500 mL/day.

Table 11. It shows the average measured parameter values for the selected substrates

Rate of biogas l	pH	Moisture, %	COD, mg/l	Inorganic materials, %	EC, μs/m	Organic matter	C%	N%	C/N
4.52	6.49	91.59	14656.2	1.93	19.24	6.46	24.7	2.49	9.9

Table 12. Physicochemical parameters of the feed (Kumari et al., 2018)

Parameter	KW + SS	YW + SS	FW + CM	DWW + CM
pH	4.6	7.59	6.54	6.86
T, C	36.5	37.1	36.2	35.5
TS, %	84	82.6	83.28	85.42
VS, %	88.27	71.45	85.88	86.21
VFA, mg/L	3125	2854	1678	2482
COD, mg/L	61382	9288	5692	6542

The ideal amount of gas was approximately 7400 mL/day.

The performance of the anaerobic digestion process in our study was initially linked to the substrate used (co-digestion) to achieve the best C/N ratio by using food waste with a low C/N ratio with cow manure with a high ratio. The fermentation process was carried out in the UASB reactor at a temperature of 31 °C and during one stage, and the pH values ranged between 7–6.5 while (Xing, 2020) and the pH values ranged between -6–8 so that the effect of changing the pH on methane production was studied, while (Petracchini et al. 2017) sought to avoid its effect through fermentation in two stages.

The C/N values ranged between 10–20 for the common substrate, which is the optimal ratio for achieving the optimal production of methane gas, and decreased during fermentation to 9 as a result of the decomposition of organic matter, as confirmed by (Singh, 2017; Sunny, 2018). In the three experiments, biogas production started from the sixth day, with the methane percentage gradually increasing to reach 90–95%,, while the CO_2 values ranged within the range of 50%, and the CO values ranged between 6–10% and the concentration of 2H is within the range 20–30%. Our results in CO_2 and CH_4 are similar to Petracchini et al. 2017, and exceed it in the resulting H_2 concentrations, which were 5.5%.

CONCLUSIONS

The experiments showed that the optimal ratio in our study was FW/CM = 0.25, which produced the best biogas production. It is important to note that the composition of food waste used in anaerobic digestion, which ranges from kitchen waste to fruit waste and restaurant waste, is important due to its diverse properties and direct impact on the fermentation process. We found that results vary from country to country due to the diverse composition of this waste. The composition of food waste is a vital factor in the digestion process, significantly affecting the efficiency and production of methane. The composition of this waste varies from region to region for several reasons, including the types of food consumed, the culture of the country, agricultural practices, and more.The use of the UASB reactor was encouraged, as it plays a role in preventing the application (stirring) of fermented material through the mechanism of operation of the reactor, confirming the necessity of developing traditional anaerobic digestion techniques. When monitoring the daily operation of the reactor, we noticed the role of pH, temperature, and the C/N ratio in the production of pure methane. Given that Syria is a country characterised by a large amount of animal wealth and an excess amount of food waste, this leads us to use animal manure and food waste as a means of producing biogas.

The single-stage digestion process was chosen for its simplicity and operational efficiency: it requires less infrastructure and is easier to operate than multistage systems. With a food waste-to-cow manure ratio of 0.25, this single-stage process ensures the continuous maintenance of the conditions necessary for maximum methane production. The common substrate also compensates for the loss of nutrients from anaerobic bacteria that occurs when the two are digested separately.

We also recommend expanding the application of UASB reactor technology to include the digestion of solid waste, animal waste, and sewage sludge. Furthermore, the characteristics and composition of waste in each country must be investigated and efforts must be made to understand the biological processes of anaerobic bacteria to maximise their use.

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