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# Biogas Production Efficiency and Financial Feasibility of Small-Scale Floating Drum Biogas Units for Rural Communities: Palestine as a Case Study

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**ABSTRACT**

*The production of biogas using small-scale floating drum biogas units which an aerobically digest organic waste from various sources provides significant benefits over other techniques of bioenergy production for domestic as well as for farmers in rural communities. The experiment was conducted using a 1500 L in size floating drum biogas unit. Four different waste mixtures were tested for their biogas and fertilizer production. Results obtained from this experiment showed that the highest biogas yields during 16 days of unit operation were sheep manure (22.9 kg), cow manure (22.6 kg), poultry manure (20.8 kg), and food residues mixed with cow manure (19 kg), respectively. Non-linear model analysis was used to predict gas quantity produced as a function of mixture type, temperature, and time. And a plot of measured versus predicted biogas quantity was drawn and proved the good fit of the depicted nonlinear model. An experiment was performed to estimate a conversion factor for the family requirements of biogas if it replaced LPG. Experimental results indicated that the conversion factor between LPG and biogas was 1.79, or the 12 kg bottle of LPG is equivalent to 44kg of biogas. The produced biogas quantity was found enough to cover the Palestinian family's needs of cooking fuel. In the economic evaluation of the biogas unit, the initial investment to construct a floating drum biogas unit was 377 US$(and the monthly running cost was estimated at less than 4 US$). The simple payback period was 20 months which was considered reasonable.*

**Keywords:** *Small-Scale floating Drum Biogas Units, Renewable Energy, on-farm Waste Management, Rural Palestine.*

## INTRODUCTION

Energy is a key driver for agriculture, industries, and urban service sectors that influence economic development [1]. With the globally increasing population, urbanization, and industrialization, the use of fossil fuels (more than 85% of the total energy consumed currently) [2] has dramatically increased resulting in depletion of those non-renewable resources, harming the environment, affecting materials and people's health and social belongings. Consequently, the interest in the search for an alternate cleaner source of energy was growing worldwide. On the other hand, environmentalists are always concerned about finding an energy source that is environmentally sustainable, economically feasible, and socially acceptable.

Anaerobic Digestion (AD) is a technology with proven efficiency, is widely used in the stabilization of industrial wastewater, urban solid waste, animal manure, and sewage sludge [3].

Different AD process types can be applied for biogas generation including dry and wet fermentation systems [4-6], Batch or Continuous systems, Single-Step or Multi-Step, and Co-digestion with animal manure or digestion of solid waste [7].

In AD, several factors were found affecting reactor efficiency and performance including the carbon to nitrogen ratio in organic waste (C/N)[8], AD mixture: its dilution ratio of solid and liquid, its pH Value [9], its mixing/agitation level [10], and its temperature (Mesophilic or Thermophilic digestion) [11,12], loading rate of organic waste to the AD reactor, the retention time that the organic waste remains in the AD digester, and risk of toxicity from materials and gases emitted from AD process [13].

Biogas produced from AD is characterized based on its chemical composition and the physical characteristics which result from it. It is primarily a mixture of methane ($CH_4$, 55-70%) and inert carbonic gas ($CO_2$, 30-42%) and may have small amounts of water vapor ($H_2O$) and hydrogen sulfide ($H_2S$), moisture, and siloxanes [14]. However, the name "biogas" gathers a large variety of gases resulting from specific treatment processes, starting from various organic waste - industries, animal or domestic origin waste, etc. [15].

There are several advantages of renewable energy production using AD of organic waste including its contribution to the reduction of greenhouse gases and climate change minimization [16], mass reduction of solid/organic waste, odor removal, pathogen reduction, less energy use, and more significantly, the energy recovery in the form of methane [17-19]. Using AD diversifies energy access, improves energy security [20], reduces environmental negative impacts, reduces health risks associated with air pollution of fossil fuel use [21,22], and improves sanitation conditions[23]. In addition to that AD provides economic benefit to society and enhances economic development [24-26]. It should be noted that one of the major advantages of AD is its adaptability to deal with a wide range of organic matter types [27].

Disadvantages of AD systems are limited and rise from health risks associated with the effluent gaseous, liquid, and solid emissions and residues from the process which might include potential chemical contaminants [28,29]. The concentrations of these impurities are dependent on the composition of the substrate from which the gas was produced [30]. Another disadvantage of AD is its relatively large capital, installation, and operational and maintenance costs [31-33].

The success of biogas plants (projects) in an area depends on the availability of organic materials, construction cost, available energy sources and its costs, availability of experience, knowledge, and know-how of AD process and digestors, ambient climate conditions especially temperature, and acceptability for people constructing these plants [34].

Anaerobic digestion social and economic merit relies on conditions dependent on a variety of factors such as organic waste quality, site-specific circumstances, availability of outlets / markets for the energy produced, energy prices and taxes, energy purchase tariffs, costs of alternatives/taxes on alternatives, policy, land prices, markets for compost and digestate and level of capital and labor costs in each country [35].

Economic production of biogas can be achieved for both large- and small-scale applications. Hence, it can be designed to fit into rural, urban, as well as regional and nationwide energy needs making it a versatile source of energy [36-39].

Annual bioenergy production across the Middle East region has increased [40,41]. Biomass energy can be generated from different sources, such as animal or human waste or crops, and municipal solid waste. In Palestine, the potential energy in these types of waste streams is estimated at 800 GWh per year [42,43]

A review of municipal solid waste (MSW) management indicated that the average MSW generation in Palestine is 0.94 kg/capita/day, with an increase of approximately 1% per capita per year. The waste collection rate has reached 91.5% of households in 2013. The solid waste disposal in sanitary landfills was found to be 33% of the total waste [44-46].

There were limited studies found globally on evaluating small-scale floating drum biogas units including their environmental impacts [47,48], their application and energy services[49-51], addressing their problems [52], their modeling and optimization[ 53-55], and their environmental benefits [56,57].

At present political conditions, Palestine is not allowed to explore and has no fossil (gas and/or oil) sources. Consequently, Palestine is fulfilling its energy needs of natural gas through imports from Israeli companies.

The main objective of this study is to evaluate, assess, and model the biogas production from small-scale biogas plants digesting on-farm and/or domestic organic waste as an alternative source of energy for rural Palestinian communities.

## METHODS AND MATERIALS

### Experimental Setup

### Biogas Unit Design and Installation

A small-scale floating drum biogas unit consists of two PVC black tanks, galvanized metal base, waste shredder, and valves and fittings. Figure 1 is an illustration of the developed biogas unit with all its components. The unit was designed by the first author in such a way that the floating drum was made of perforated plastic (the lower part facing the bottom of the external-digesting tank) to allow smooth movement of the produced gas to the top of the drum to be collected in addition to smoothing the movement of the drum up as the gas accumulates in it (See Figures 1 and 2).

The PVC tanks were made by a local company, Royal Industrial Trading Co, Hebron, Palestine (https://royal.ps). The unit design was made to allow (1) The shredding of the input organic matter to make it easily available to microorganisms and widely dispersed through the outer PVC tank, (2) Valves were installed to allow measurement of the fertilizer/digestate quantity and the gas produced, (3) the diameters of the PVC tanks were made close enough (with only 7 cm open to the atmosphere space between the two) to allow smooth movement of the drum within the outer tank and to minimum produced biogas from escaping from the open area to the atmosphere, and (4) the size of the unit was made to absorb the organic waste daily produced by a single Palestinian family of about 12 kgs.

The following is a technical description of the developed biogas unit (See Fig.1):

- The two PVC black tanks were of 1000 L(inner drum) and 1500 L (outer digesting tank) size
- The valves and fittings were made of heavy-duty PVC to minimize operation and maintenance problems
- The base or table holding the unit was 15 cm off the ground and was made of galvanized steel.
- The shredder was also heavy-duty to allow long term use and was connected through PVC pipe to the bottom of the digesting tank
- A ½" brass gas valve was placed in the middle of the drum. The valve was connected to a 24 Liter, 2HP compressor and electronic balance to allow biogas withdrawal and measurement.
- Two layers of small hard rock stones (to minimize dissolution) of about 2" in diameter were placed at the bottom of the digestion tank to serve as an adequate surface for microorganisms' growth.

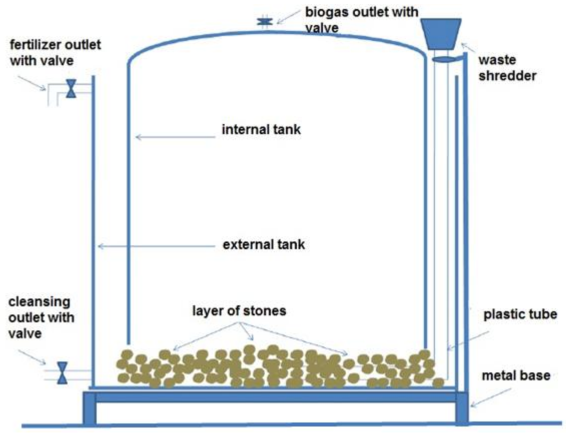


**Fig1.** *Schematic of the Designed Small-Scale Floating Drum Biogas Unit*

The biogas unit was connected to the air compressor using a special gas pressure tube and fittings. The biogas unit was placed in a greenhouse to enhance the temperature stability of the digestor.

**Fig2.** *A Picture of the External (Right) and Internal (Left) PVC Tanks*


**Fig3.** *The Air Compressor with the Electronic Balance Setting*

## Experiment Program

The experimental program consists of two steps: the start-up period, experimental stages with four waste proportions

- Initially, at start-up, half of the digesting tank of the biogas unit was filled with cow manure and water on a 1:1 ratio. No additional waste was added to the tank for 30 days to allow microorganisms to grow and to stabilize the biogas unit. During this period the biogas unit generated biogas and the generated biogas was emptied several times.
- The experiment was divided into four stages. Each stage has a distinct waste type.
- Table1 shows the waste mixture used at each stage. The purpose of these stages is to quantify the continued biogas generation from operating the biogas digester using different mixtures. In each stage and for sixteen days, 12 kg of organic waste was added daily to the digestion tank at 7.00 AM.

**Table1:** *Experimental stages by Type and Quantity of Waste, Water Added, and Experimental Period*

| Stage number | Waste added | | Water added (kg / day) | Addition period (day) |
|---|---|---|---|---|
| | Type | Quantity (kg / day) | | |
| 1 | Cow manure | 6 | 12 | 16 |
| | Food residues | 6 | | |
| 2 | Cow manure | 12 | 12 | 16 |
| 3 | Sheep manure | 12 | 12 | 16 |
| 4 | Poultry manure | 12 | 12 | 16 |

Organic waste of each experimental stage was mixed with water on a 1:1 ratio before feeding it to the biogas digesting tank. Twelve kilograms of organic/domestic waste was added to the digesting tank daily for 14 days, the experimental period of every stage (or waste mixture). The biogas was collected 4 times a day. The collection was 3 times at daytime and 1 time at night. This frequency is due to the variation in temperature between daytime (higher because of sunshine) and nighttime.

## Measurements and Lab Analysis

### Biogas Collection, Storage and Weighing

As the waste digests, the biogas form and rises. Most of the generated biogas end up in the upper tank (the gas collector tank). To weigh the biogas, an air compressor was used. The biogas was collected using the air compressor four times a day and weighed using a digital balance. The temperature of the digestate and the surrounding air was recorded daily.

### Temperature Measurements

Ambient temperature was measured using a mercury thermometer fixed on the side of the greenhouse, while the digestate temperature was measured by taking a small sample of the digestate from the bottom outlet and measuring the temperature immediately using a digital thermometer.

### Lab Analysis

For each stage of the four stages, a biogas sample was taken from the floating drum outlet. The samples were supposed to be tested to measure their methane content using GC (Gas Chromotography).

## Results And Discussion

The total daily biogas produced from each stage and their ranks were listed in Table 2.

It is apparent from the data in Table 2 that experimental stage 3 (sheep manure) produced the largest biogas quantity during the experiment followed by stage 2 (cow manure), stage 4 (poultry manure) and stage 1 (mixed cow and food residues) respectively.

### Experimental Stage 1 results: Cow manure mixed Equally with household waste

The daily biogas produced was ranging from 1080 to 1300 gm/day. The average daily biogas production rate during 16 days was 1184.7 gm/day with a 65.6 standard deviation. A presentation of experimental stage 1 daily biogas produced is given in Figure 4. From Figure 4, it was obvious that stable biogas production reading was observed after the fourth day of unit operation.

The total quantity of biogas produced during this stage (16 days) was 18.955 kg.

Based on the daily feeding rate of organic waste to the biogas digester (12 kg), it was estimated that 0.099 kg biogas was produced per kg of organic waste added or 9.9% of organic waste was converted to biogas.

**Table2:** *Detailed Biogas Quantities Produced from Different Waste Mixtures*

| | Biogas quantity produced (gm/day) | | | |
|---|---|---|---|---|
| day number | Stage1 (mixed cow + food) | stage 2 (cow) | stage 3 (sheep) | stage4 (poultry) |
| 1 | 1080 | 1040 | 1240 | 1520 |
| 2 | 1120 | 1425 | 1320 | 1300 |
| 3 | 1095 | 1330 | 1250 | 1370 |
| 4 | 1300 | 1505 | 1420 | 1400 |
| 5 | 1120 | 1520 | 1520 | 1150 |
| 6 | 1200 | 1460 | 1450 | 1220 |
| 7 | 1240 | 1390 | 1320 | 1200 |
| 8 | 1205 | 1400 | 1500 | 1200 |
| 9 | 1230 | 1425 | 1450 | 1230 |
| 10 | 1185 | 1290 | 1600 | 1300 |
| 11 | 1240 | 1380 | 1520 | 1370 |
| 12 | 1120 | 1530 | 1530 | 1320 |
| 13 | 1215 | 1485 | 1500 | 1300 |
| 14 | 1125 | 1470 | 1470 | 1280 |
| 15 | 1250 | 1500 | 1370 | 1290 |
| 16 | 1230 | 1475 | 1480 | 1320 |
| Total (gm) | 18955 | 22625 | 22940 | 20770 |

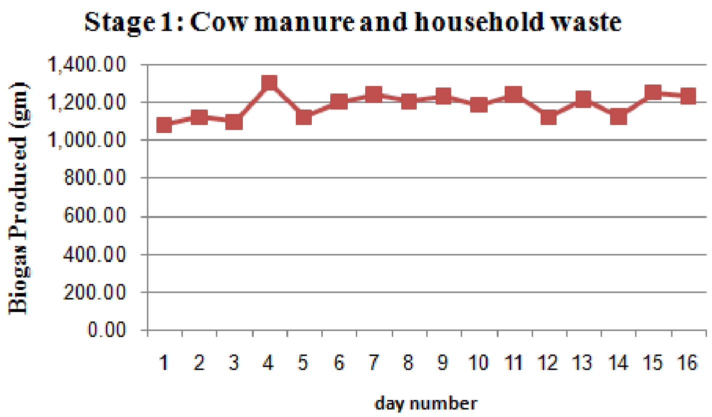


**Fig4.** *Daily Biogas Produced in Experimental stage 1 [gm/day]*

## Experimental Stage 2 Results: Cow Manure

The daily biogas production during this stage ranged from 1040-1530 gm/day. The average daily biogas production rate during 16 days was 1414.1 gm/day with a 120.8 standard deviation. The minimum daily biogas production was on the first day. However, biogas production stabilized after the first day indicating the quicker digestion of cow manure. A presentation of experimental stage 2 daily biogas produced is given in Figure 5

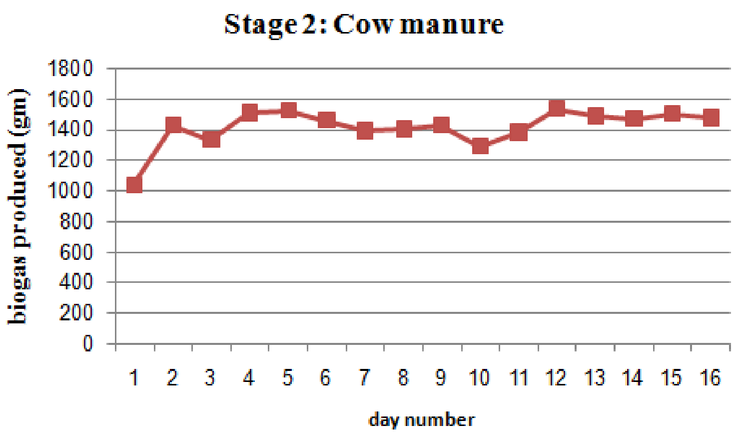


**Fig5.** *Daily Biogas Produced in Experimental stage 2 [gm/day]*

The total quantity of biogas produced during this stage (16 days) was 22.6 kg. Based on the daily feeding rate of the biogas digester, it was estimated that 0.117 kg biogas was produced per kg of organic waste added or 11.7% of organic waste was converted to biogas

### Experimental Stage 3 Results: Sheep Manure

At this stage, a quantity of 12 kg of sheep manure and 12 kg of water were mixed and added daily. The average biogas production rate during 16 days was 1433.8 gm/day with a 105.2 standard deviation. Figure 6below illustrates the daily biogas quantity produced by time at this stage.

The biogas production during this stage ranged from 1240-1600 gm/day. With the minimum production at day number 1 and the maximum at day number 10. The average biogas production rate during 16 days was 1433.8 gm/day with a 105.2 standard deviation. A presentation of experimental stage 3 daily biogas produced is given in Figure 6.

The total quantity of biogas produced during this stage is almost 22.9 kg biogas. Based on the daily feeding rate of the biogas digester, taking cow manure and household waste as the waste input, the average kilograms of biogas produced per kilograms of waste added was calculated at 0.119 kg biogas per kg waste. This is almost 12% of the organic waste added is converted into biogas.

### Experimental Stage 4 Results: Poultry Manure

The biogas production during this stage ranged from 1520-1150 gm/day. With the minimum production at day number 5and the maximum at day number 1.The average biogas production rate during 16 days was 1298.1 gm/day with a 90.6 standard deviation. A presentation of experimental stage 4 daily biogas produced is given in Figure 7

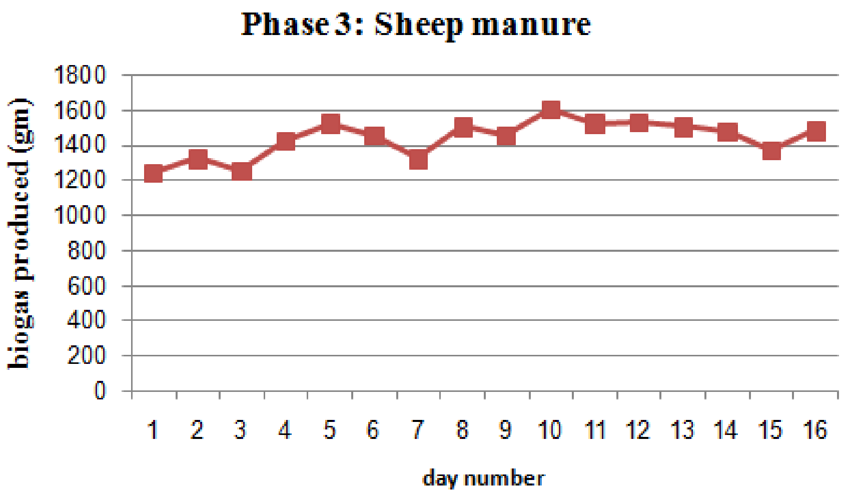


**Fig6.** *Daily Biogas Produced in Experimental stage 3 [gm/day]*

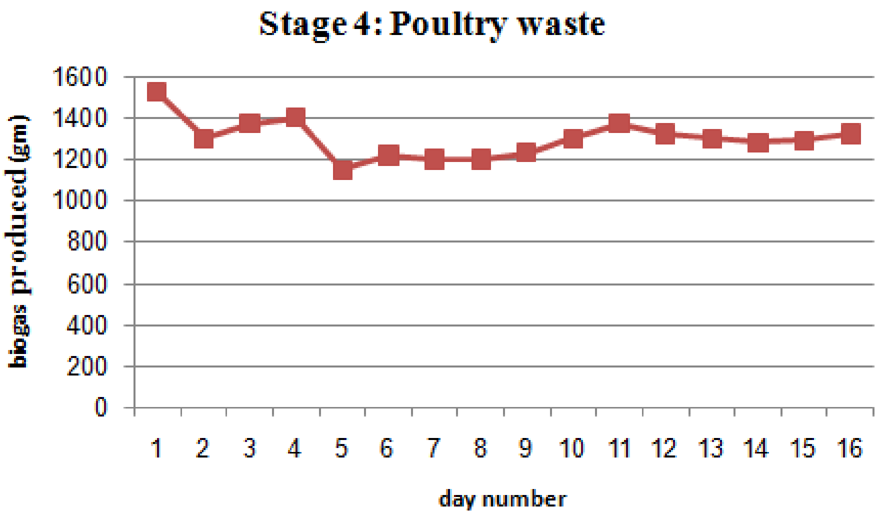


**Fig7.** *Daily Biogas Produced in Experimental stage 4 [gm/day]*

The total quantity of biogas produced during this stage is 20.8 kg. Based on the daily feeding rate of the biogas digester, the average kilograms of biogas produced per kilograms of waste added was estimated at 0.108. This means that10.8% of the organic waste added was converted into biogas.

## Comparison between the Four Experimental Stages

The table below summarizes the average daily [gm] and total monthly biogas quantity produced [kg] from different waste mixtures through the sixteen days experimental periods, and the percent of converted organic waste to biogas. From the results of the four experimental stages the following observations were made:

- The biogas produced from the digestion of each waste type is different from the others.
- Biogas produced stabilized quickly and no big variations were observed over the experimental period.
- Biogas produced was ranging within+/- 100 gm/day for all four stages and over the experimental period.
- Minimum biogas produced was greater than 1 kg/day for the four experimental stages.

**Table3:** *Experimental Stages Results by Average and Total biogas produced and Percent Waste Converted*

| Stage # | Organic Waste added | Average biogas produced (gm/day) | Total Biogas Produced kg | Percent converted waste | Rank |
|---|---|---|---|---|---|
| 1 | Mixed Cow Manure and Food Residues | 1187.7 | 18.99 | 9.9 | 4 |
| 2 | Cow Manure | 1414.1 | 22.6 | 11.7 | 2 |
| 3 | Sheep Manure | 1433.8 | 22.9 | 11.9 | 1 |
| 4 | Poultry Manure | 1298.1 | 20.8 | 10.8 | 3 |

## Nonlinear Biogas Production Model

It was found that control of biogas plants is a complex and challenging task due to the nonlinearity of the anaerobic digestion process involved in the conversion of biodegradable input material (various diverse organic waste input) to biogas [58-64].

A nonlinear least-square procedure giving least-squares or weighted least square estimates of the parameters was conducted using Statistical Analysis Systems, SAS [65]. The tested model finds the relationship between biogas production from the four mixtures and both operating digester temperature and digesting time. Other variables for each experimental stage were fixed such as organic waste loading rate and digestor size and not entered into the model.

The SAS nonlinear analyses model was symbolized as:

$$\mathbf{Y = C*(Time)^{X1} * (Temp)^{X2}},$$

Where,

Y is produced gas in mg

C is a constant

X1 and X2 are exponents

The model output is given in Table 4.

It was noticed in the nonlinear model output (Table 4) that the values of the exponents X1 and X2 for the four experimental stages were somehow close indicating a homogeneous effect of digesting temperature and time while the constants were variable due to biogas production data diversity.

**Table4:** *Nonlinear Model SAS Analyses Results*

| | **C** | | **X1** | | **X2** | |
|---|---|---|---|---|---|---|
| | **Estimate** | **SE** | **Estimate** | **SE** | **Estimate** | **SE** |
| Stage 1 | 10.57 | 13.39 | -0.00116 | 0.0156 | 1.3829 | 0.3761 |
| Stage 2 | 1.1198 | 1.544 | 0.0256 | 0.0165 | 2.0345 | 0.3995 |
| Stage 3 | 0.0537 | 0.0473 | 0.0369 | 0.00648 | 2.898 | 0.2534 |
| Stage 4 | 1.2488 | 2.7576 | 0.00594 | 0.0214 | 2.007 | 0.631 |

The measured and predicted values of produced biogas are presented in Figure 8. It is evident from Figure 8 that there is a good fit between measured and predicted by the model biogas values.

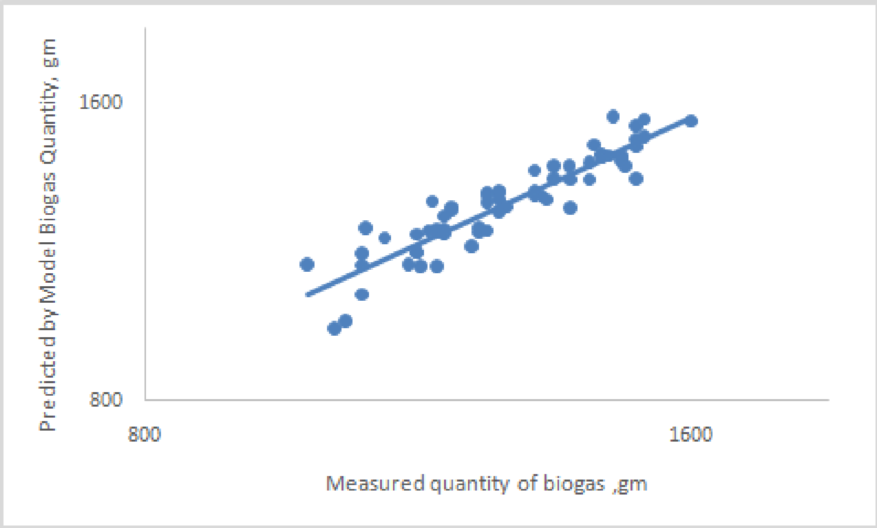


**Fig8.** *Plot of Predicted Biogas Production by the Nonlinear Model Versus Measured Biogas Values*

Using the obtained nonlinear model, it will be possible to predict the produced quantity of biogas and therefore to advance the design of small-scale floating drums biogas units by changing digestion time and temperature.

SAS software was used to estimate the least-square means of biogas production from the four waste mixtures and to plot measured versus predicted biogas production. The obtained least-square means were1310.9[a], 1349.2a, 1344.3[a] and 1326.2[a] for experimental stages 1 to 4, respectively. It was indicated that there is no statistically significant differences at the significance level ($\alpha$ = 0.05) in biogas production for the four experimental stages or the different waste mixtures (See Table 3).

## Biogas from AD Unit versus Market Liquefied Petroleum Gas (LPG)

LPG is composed primarily of propane and butane, while biogas contains methane. LPG, vaporized and at atmospheric pressure, has a higher calorific value (44 MJ/kg) than biogas from AD unit(32-36 MJ/kg)[66].

The ratio between the heat content of LPG to the average heat content of methane is:

(44 MJ/kg LPG) / (34 MJ/kg biogas) = 1.3.

An experiment was conducted to estimate a conversion factor between the family requirements of biogas if it replaced LPG for the same process and time.

The results indicated that the AD unit biogas weight required for producing continuous flame – strong enough to cook rice for the family– for one and a half hours was 280 gm. While the weight of LPG required for producing the same continuous flame for the same period was 120 gm.

The conversion factor= (/ biogas weight/ LPG weight) / 1.3= (280/120) * 1.3 = 179 needed AD biogas for LPG

According to the Palestinian Central Bureau of Statistics (PCBS) [67] the average LPG consumption by Palestinian family between 14 and 26 kg, the equivalent biogas need of the same family would be 25 to 47 kg of biogas. This indicates that the max biogas produced from a small floating drum biogas unit with 12 kg organic waste input of 22.9 kg/16 days (see Table 5 ) or a total of 43.94 kg of biogas/month represents about the maximum family biogas monthly need. Accordingly, the 12 kg of organic waste feed to the AD digester would produce enough biogas to fulfill the monthly rural community family needs.

## Financial Evaluation of a Biogas Digester

The financial analysis for constructing a family biogas unit is based on the design of the biogas unit used in this research study and on a waste feeding rate of 12 kg/day (See Figure).

The cost for constructing the designed and developed small-scale floating drum biogas unit was estimated at 1300 NIS. A description of the cost components was given in Table 5.

**Table5:** *Small-Scale Floating Drum Biogas Unit Cost Estimation*

| Component Description | Cost (NIS) |
|---|---|
| 1500 L PVC tank | 420 |
| 1000 LPVC tank | 370 |
| Gas and fertilizer valves and connectors | 200 |
| Galvanized Metal base | 180 |
| Plastic pipes | 80 |
| Miscellaneous | 50 |
| **Total** | 1300 |

As shown in the previous table, the initial investment to construct a floating drum biogas unit is 1300 NIS (about 377 US$).The electric waste shredder was not included in estimating the cost of a biogas unit, because it was concluded that using an electric waste shredder is not practical in farms (it requires an electricity source). Which is not always available in place).

The monthly running cost for operating the family biogas unit was minimal and estimated at 11 NIS (less than 4 US$) and detailed as follows:

- The cost of hiring a laborer once a year is approximated to 120 NIS/year; that is 10 NIS/month.
- The water needed to operate the biogas unit is 12 kg/day. According to the Palestinian Central Bureau of Statistics PCBS [68], the price of 1 $m^3$ of water is 2.6 NIS., and accordingly, water monthly cost is equal to 0.91 NIS.

## Biogas and Fertilizer Revenue

The AD, small scale floating drum, biogas unit produces both biogas and organic fertilizer. The economic benefits from biogas are difficult to define and/or assess because produced biogas as a fuel cannot be sold on the open market. The value must be used within the farm. Accordingly, it was assumed that the produced AD biogas to replace LPG use in the farm. The revenue from biogas and organic fertilizer can be estimated as follows:

1. Biogas revenue: the biogas produced is sufficient to fulfill the family's needs of cooking fuel; this means it is sufficient to replace the LPG that is usually used for cooking. An average Palestinian family needs one 12 kg bottle of LPG per month for cooking. The price of 12kg bottle LPG in Palestine on average is 65 NIS and this was considered as the AD biogas unit monthly revenue.
2. Fertilizer revenue: the biogas unit produces 22-23 liter of organic fertilizer daily (after deducting the weight of the biogas produced from the feed of 12 kg organic waste and 12-liter water). The fertilizer produced can save the family the cost of buying fertilizers from the market for their farm or garden and they can give or sell the surplus quantities to neighboring farmers. It was difficult to assess the value of the fertilizer produced and there was limited testing made on this part in this research and consequently, it was difficult to compare the AD-produced fertilizer with commercial ones. It was assumed that the AD-produced fertilizer represents a bonus benefit to the farmer.

## The Simple Payback Period

The simple payback period is calculated as follows:

The simple payback period = initial investment / monthly revenue

The simple payback period = = 1300 / 65 = 20.0 months,

This means that the Palestinian family will get back their initial investment of constructing a floating drum biogas unit in less than 2 years. This estimate is considered reasonable. Also, this quote agrees with published data of 1.8 years, and the period is considered reasonable [70].

It was reported that a close payback period for constructing family-sized biogas units in Palestine; they both reported 1.8 years as the payback period [71,72].

# CONCLUDING REMARKS

As a result of the main findings of this research, the following concluding remarks were observed:

- The small-scale floating drum biogas unit is a suitable way to dispose of organic waste produced on the farm and produced biogas and fertilizer for the farmer's use and benefit.

- The daily biogas quantity produced from the four experimental stages (four organic waste mixtures) was 1.18-1.43 kg/day.
- The 12 kg of organic waste feed to the digestor would produce enough biogas to fulfill the monthly rural community family needs.
- The initial investment to construct a small-scale floating drum biogas unit was 377 US$, the monthly running cost was less than 4 US$.
- The simple payback period is 20 months and is considered reasonable. The produced fertilizer was considered as bonus revenue for the farmers and not included in the payback period estimation.
- Biogas technology should be encouraged and promoted in rural Palestinian communities due to several advantages.

## Acknowledgments

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