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Gas output of HomeBiogas7.0 in province1 (Terai region) of Nepal and HomeBiogas7.0 model vs GGC-2047

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Abstract

This paper shows a practical way of producing biogas using a HomeBiogas7.0 system in the rural areas of Nepal. Furthermore, it compares this new method with traditional biogas technology (a fixed dome apparatus). The HomeBiogas system has a number of very attractive attributes. It is very portable, easy and fast to install, requires little maintenance, and there is no chance for slurry to enter the pipelines. Furthermore, it has a biogas filter, short installation time (<6 h), the amount of available biogas can be visually determined and its parts are recyclable. It is earthquake-proof, a large number of units can be installed in a short time. Furthermore, women can be empowered through job creation since the work requires little heavy labor. The main aim of the current research is to determine the performance, biogas composition and output of HomeBiogas7.0 systems in the Terai region of Nepal and compare these results with those of existing fixed dome biogas plants. This objective was achieved by installing eight HomeBiogas7.0 plants with gas flow meters and frequent visits to the sites/plants in Province1 of Nepal. A biogas productivity of 0.961 m^3/day or 0.223 $m^3_{biogas}/m^3_{digester}$ was attained with a feed rate of 33±12 kg/day of animal manure at an ambient temperature of 25 °C. A HomeBiogas7.0 system has the energy value of 13.4 kg of liquefied petroleum gas (LPG)/month with an energy production of 5.766 kWh/day. Biogas production from a HomeBiogas7.0 system in the winter season (0.638 m^3/day) was less than in the spring (1.093 m^3/day) and that was smaller than in the rainy season (1.158 m^3/day). On average, cooking requires 3.56 h/day. The energy production of this system is sufficient for rural, semi-rural areas for families to cook food with biogas having a methane content of 56.1%.

Keywords: Anaerobic digestion, Fixed dome, GGC-2047, HomeBiogas7.0, Manure, Nepal

1. Introduction

Biogas is an important source of energy. It can partially replace the current energy demand in a sustainable manner [1, 2]. The first biogas plant was installed in 1955 and this sector has been developed and promoted in Nepal. Nepal's constitution divides the county into seven provinces. The country has a geographical area of 147,516 square kilometers with three ecological regions. These include the Himalayan region (colder climate), a mountainous region, and the Terai region with a warmer climate. Nepal is a developing country that is located between two large countries, China and India. In the country, 69% of the people use traditional sources of fuel such as firewood, agricultural residues as shown in Figure 1. Another 28% of the population relies on commercial energy sources including petrol, diesel and kerosene, while 3% use renewable energy sources such as hydropower, solar, wind and biogas. Most of the energy is used for residential purposes including cooking, heating, and lighting. The caloric value of biogas is 21-24 MJ/m^3 [3].

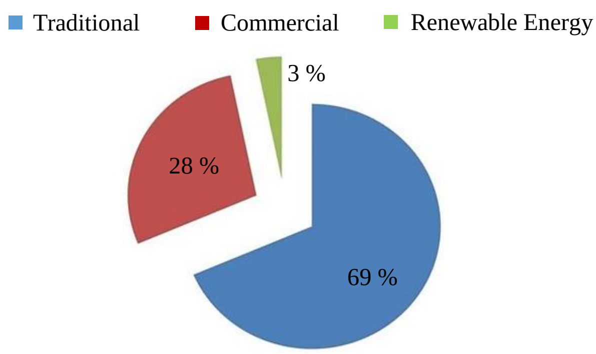

Figure 1 Energy consumption in Nepal 2018/19 [4]

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Nepal is an agricultural country. More than 80% of the population of Nepal is employed in agriculture [5]. Generally, Nepalese families who live in rural areas have animals such as cows, goats, oxen, and buffalo. Still, in Province6, 89.5% of people use firewood and cow dung cake as cooking fuels, as shown in Table 1. In Province3, the lowest proportion of people, 38.8%, use firewood and cow dung cake for this purpose.

Table 1 Proportion of people using firewood and dung cake in the provinces of Nepal 2018/19 [6]

SN	Provinces	People using firewood and cow dung cake for cooking (%)
1	Province1	70.3
2	Province2	84
3	Province3	38.8
4	Province4	58.9
5	Province5	65.3
6	Province6	89.5
7	Province7	82.5

Nepal has the capacity to install about 2 million household biogas plants for clean cooking [7]. The decision to install a biodigester is affected by the education of the household head, income, cost of cooking fuel, and the number of cattle [8]. Numerous nations that have introduced family-scale biodigesters found that around 50% of the new plants became non-functional due to a lack of repairs and support offices [9]. Household biodigesters range in size from 2-10 m^3 volumes that can yield 0.5 m^3/m^3 of biogas/digester volume [10-12].

1.1 Process of biogas production

The stages of biogas production are hydrolysis, acidogenesis, acetogenesis, and methanogenesis [13] as shown in Figure 2. However, more broadly, the process can be divided into two phases, acid and gas generating phases [14]. Balance need to maintained regarding behavioral, nutrient needs, growth kinetics, and environment conditions necessary for acid and gas forming microorganisms. Otherwise, there may be inhibition of methane generation [15].

Hydrolysis

Hydrolysis is the initial stage of the anaerobic digestion (AD) process. It involves the transformation of larger molecules of carbohydrates, proteins and fats to simpler forms of sugar, fatty acids, and amino acids, respectively. Biologically produced enzymes are used in transformation processes [16] and these enzymes are present in the microorganism cell walls [17]. Transferred enzymes can be used as substrates by microorganisms [16].

Acidogenesis

Acidogenesis is the second stage and is known as the fermentation stage. The output of hydrolysis is converted into organic acids, alcohols, hydrogen, carbon dioxide, and ammonia [18]. Additional water and rumen fluids are added to the feedstock enhance biogas production, supporting the hydrolysis and acetogenesis stages [19].

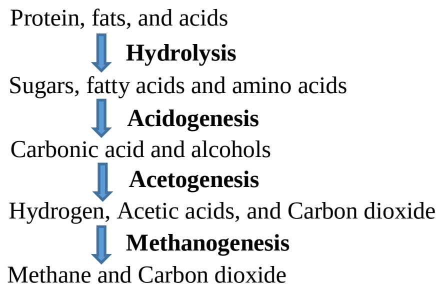

Figure 2 Steps in the anaerobic digestion process

Acetogenesis

In the acetogenesis stage, the acidogenic outputs are oxidizing into simpler forms. There is a need for close balance among acetogenic and methanogenic microorganisms of the anaerobic digestion process. Nutrients for the acetogenic microorganisms are aromatic compounds, alcohols, fatty acids, and amino acids [20].

Methanogenesis

Methanogenesis is the critical final stage of biogas production. Unfortunately, it is also the slowest process [21]. Acidogenic products are converted to methane and carbon dioxide under the conditions of anaerobic digestion [22].

1.2 Feedstocks

The feedstocks for anaerobic digestion are animal manure, grasses, sewage sludge, landfill residues, garden wastes, food wastes, and palm oil mill effluents. The process is economically viable using these resources [23]. In domestic scale biogas plants, the primary feedstock is animal manure. There is a need to have <10% total solids (TS) in the feedstock to support wet anaerobic digestion [24]. Dilution of animal manure can be made by up to 5-10% before it is fed into the biodigester, as shown in Table 2 [25].

In the case of Nepal, the most common fixed dome biogas plant is formally known as a GGC-2047 system (Gobar Gas and Agricultural Equipment Development Company Pvt. Ltd-2047). Nepal has installed 425,000 fixed dome biogas plants. On average, Nepal has built 20,407 biogas plants per year in each of the last 12 years. The biogas capacity installed from 2007/08 to 2018/19 is shown in Figure 3. The last period, includes the first 8 months of 2019.

Table 2 TS and VS of typical feedstock

Feedstock	Total solids (TS)	Volatile solids(VS)	Carbon: Nitrogen(C:N) ratio
Cow manure	9.2-29%	7.3-20%	6-29 [26]
Cow manure mixed with straw	31%	20%	39 [27]
Cow manure	14.1%	12.3%	19.1 [28]

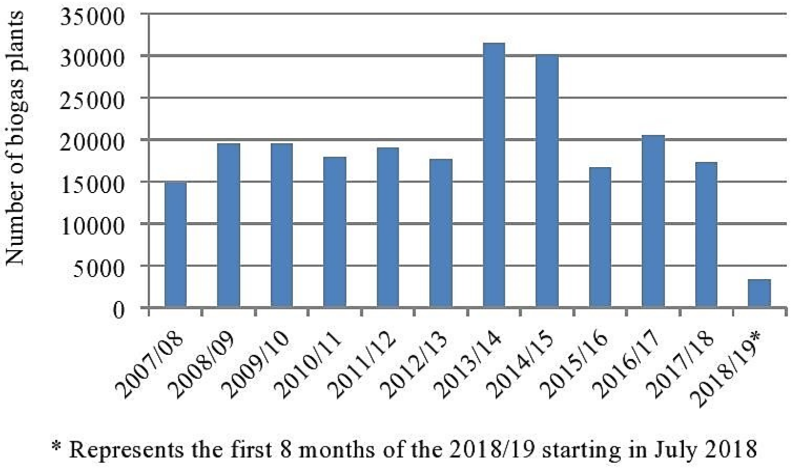

Figure 3 Fixed dome model (GGC-2047) biogas plants installed in Nepal [29]

Construction of fixed dome model biogas plants is time intensive and requires much space. Nepal is earthquake-prone, so fixed dome biogas plants are susceptible to damage from them. Many of the Nepalese people need fast, reliable and clean cooking technology to replace traditional sources of fuel (firewood, dung cake, agricultural residues). More than half of the population of Nepal depends upon the use of traditional fuels. Due to the use of these fuels, there is a huge indoor air pollution problem. Various diseases are aggravated by indoor air pollution such as pneumonia, ischaemic heart disease, chronic obstructive pulmonary disease (COPD), lung cancer, and stroke. Each year, 3.8 million people die from these diseases [30]. There are different types of biogas plants are available for clean cooking. The HomeBiogas (HBG) household system is constructed from polyethylene and polypropylene and is a tubular model biogas plant. Anaerobic Digestion (AD) turns kitchen waste and animal manure into biogas, which can be used for cooking and produce an organic liquid fertilizer for agriculture/farming. The main objective of the current research is to characterize the performance of the HomeBiogas7.0 system in the Terai region of Nepal, and compare its performance with that of a fixed dome model (GGC-2047) biogas system on the basis of the volume of biogas produced and gas composition.

2. Materials and methods

The working volume of the digester in the current research was 7 m^3 with a digester chamber that was 4 m x 1.8 m x 1.5 m (length, width, height). It was installed in different parts of Province1 of Nepal. Eight systems were installed in Province1 in the Morang, Sunsari, and Jhapa Districts. The digester chamber, in which anaerobic digestion takes place, sits on the bottom of the apparatus. A gas chamber rests on the top of this, and stores the produced biogas. The system has an inlet flange through which the feedstock is fed. There are outlet flanges for an overflow pipe for the digested slurry and another pipe to enable collection of biogas. A pressure release mechanism is used to release excess biogas when the gas chamber is full. The details of HomeBiogas7.0 are shown in Figure 4.

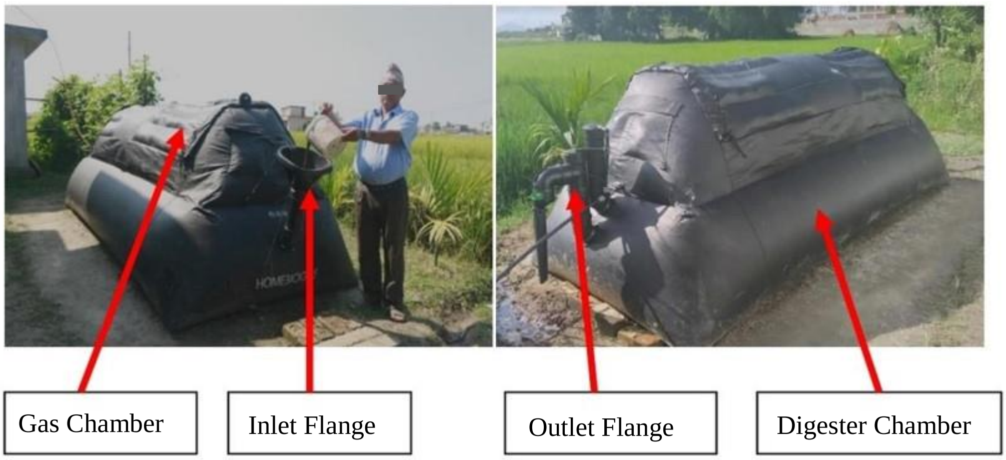

Figure 4 Details of the HomeBiogas system

2.1 Construction of a HomeBiogas system and biogas composition analysis

The HomeBiogas system accessories consisted of a digester and gasbag (attached), sandbags (2 kg), an inlet flange, outlet flange, pipe, water drainage set, and auto-ignition stoves. Site selection was done based on the maximum sunshine available for the system, distance between stoves and system (<20 m), water availability, available site area (length=5.2 m, width=2.7 m), digested slurry management, and soil compaction, as shown in Figure 5.

Figure 5 Site selection criteria

The selected area was compacted using rammers and the level was checked with a bubble level. Surfaces were made hard and level. The details of construction of a HomeBiogas7.0 system is shown in Figure 6. The bag was stretched on flat ground, while inlet and outlet flanges were connected. In a 150 L bucket, cow manure and water were mixed well and put into the system. During activation, 1500 kg of cow manure and 2800 liters of water were mixed well and put into the system. Sandbags weighing 2 kg (2 kg x 56) were put in the pocket of the gasbag. Sandbags were distributed all around the gasbag to help create pressure for the produced biogas in the system. After 7-10 days, some gas was observed in the gasbag. The initial gas was vented because it contains excessive CO_2, which makes the biogas difficult to ignite. After release of the initial gas, the gasbag was filled for a 2nd time and individual families started to burn biogas. Biogas composition in all eight systems was determined using a gas analyzer (Geotech Biogas 5000 portable biogas analyzer).

Figure 6 Construction of a HomeBiogas system

2.2 Data collection

2.2.1 Feeding amount

S_1(26.576°N, 87.998°E), S_2(26.511°N, 88.001°E), S_3(26.635°N, 87.905°E), S_4(2 6.635°N, 87.913°E), S_5(26.615°N, 88.072°E), S_6(26.454°N, 87.312°E), S_7(26.707°N, 87.212°E), S_8(26.6 0°N, 87.383°E) are the coordinates of each research system installed in Province1 of Nepal. After a family starts burning biogas, a continuous feeding system at a 1:2 ratio of well mixed manure and water were added into the system. Every family had at least one cow or buffalo. The S_2 and S_6 systems used cow manure and urine to run the system. Urine was added to water and mixed with manure. Among the eight systems, two families used tap water for cleaning and mixing with manure. The remaining families used underground water. The amounts of manure and urine fed to the HomeBiogas7.0 system is shown in Table 3.

Table 3 Feeding of the HomeBiogas system

System	Fresh manure (kg) summer and spring season feeding/day	Cow urine (liters) summer and spring season feeding/day	Fresh manure (kg)-winter season feeding/day	Cow urine (liters)-winter season feeding/day
S_1	35		35	
S_2	15	5	15	5
S_3	35		35	
S_4	30		30	
S_5	35		35	
S_6	45	15	35	10
S_7	30		30	
S_8	40		35	

2.2.2 Gas flow meter

A gas flow meter (ZhejingChint Instrument and Meter Co., Ltd., China) was installed in all eight systems. The flowmeter was placed between the system and stoves, as shown in Figure 7.

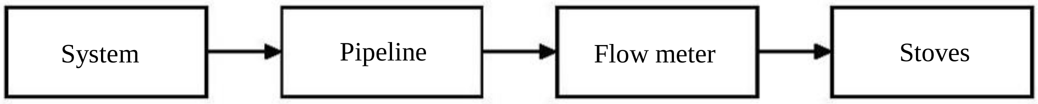

Figure 7 Experimental arrangement

The installation date of the gas flow meters was 4 December 2019. An initial reading of each system was taken. The family demographics, contact information and the number of cattle were recorded. After the installation of the gas flow meters, daily gas flow meter readings were made by contacting each household head. A monthly visit to the site each system was done. From 4 December 2019 to 29 November 2020, flow data was taken daily at around 1:00 PM. The ambient temperature was estimated from data of the Department of Hydrology and Metrology, Metrological Forecasting Division of Nepal.

2.2.3 Observation of fixed dome model

There are many fixed dome model plants installed in Province1 of Nepal. During visits to these plants, customer interaction occurred along with plant observations and a check of the biogas pressure using a dial gauge.

3. Results and discussion

3.1 Biogas production

Figure 8 shows the biogas production from Homebiogas7.0 systems on daily basis. The average gas production per day was 0.961 m^3 or 0.040041 m^3/h. The average feed rate per day was 33±12 kg of animal manure at a ratio of 1:2 (manure:water). 0.029 m^3 of gas was produced per kg of animal manure input and 0.223 $m^3_{biogas}/m^3_{digester}$ was produced from the system with an average ambient temperature of 24.79 °C. There was variation in temperature throughout the experimental period as shown in Figure 9. The temperature profile suggests that we can install the system in any region of Nepal. During times with higher temperatures, greater gas production is realized and vice versa. The cumulative gas profile increases every day as shown in Figure 10. The average values of pH, temperature, conductivity, total hardness, fluoride, chloride, ammonia, iron, manganese were 7.0, 26.2 °C, 857, 163.5 mg/l, 0.8 mg/l, 3.0 mg/l, 58 mg/l, 1.7 mg/l, and 0.4 mg/l, respectively, for ground water in the eastern plain belt of Nepal [31]. One kg of cow manure yields 35-40 liters of biogas with a hydraulic retention time (HRT) of 55-60 days at an ambient temperature of 24-26 °C, with a 1:1 ratio of manure:water [32]. The average biogas production from a 10 m^3 GGC model was 1.2 m^3/day. It was fed animal manure at a rate of 57±20 kg/day at a 3:1 ratio of manure:water, total solids of 16% (higher than the design value) and temperatures ranging from 15-30 °C [33]. The magnitude of biogas produced using ratios of manure:water was 1:3>1:2>1:1. The most gas collected in the first 30 days was with a manure:water ratio of 1:1 [18].

On average, each family did 1281.43 hours of cooking in 360 days. Considering 5% of the days idle when the family was not using the gas/stove (out of home, ceremonies and parties, weekends), the volume of gas used on average was 1.012 m^3/day during 3.75 h of cooking. The highest gas consumption was in the S_6 system, 2.098 m^3 per day, while the lowest was in the case of S_7 with 0.42 m^3, with intermediate values for other systems. The details of the number of family members, gas used in particular research systems, gas used per day per family, and total cook hours are shown in Table 4. The differences were due to feeding rate, gas needed by particular families (based on the number of family members), the standard of living and cooking habits. The HomeBiogas system has a CE certification for the highest safety [34]. The system needs installation with a proper diameter gas pipe, using no sharp material in the system. Devices must fit the HBG system. Installation needs to be outside to vent excess methane gas. There must be no sparks within five meters of the system. People must not drink the system effluent, properly dispose of the gas filter, and not place any material on the top or side of the system. A gas pressure release mechanism must activate when the gas chamber is full [35].

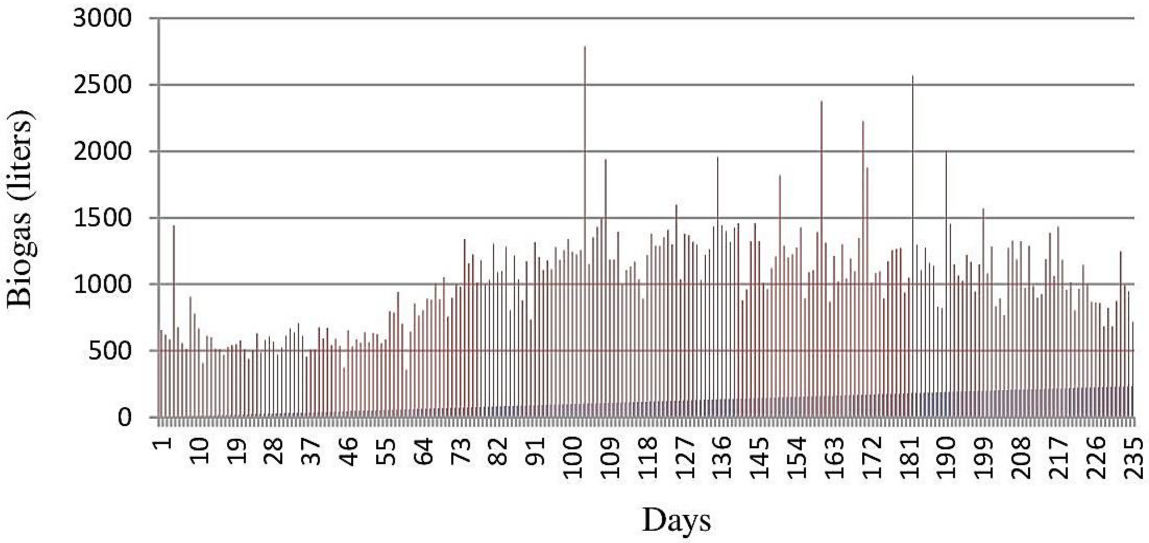

Figure 8 Daily gas output from a HomeBiogas7.0 system

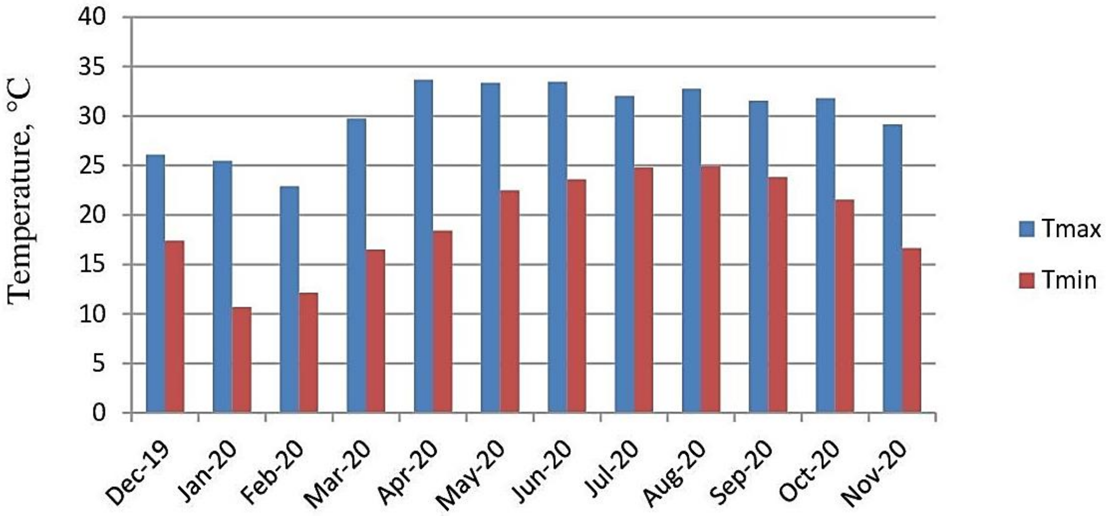

Figure 9 Monthly ambient temperatures throughout the experiment

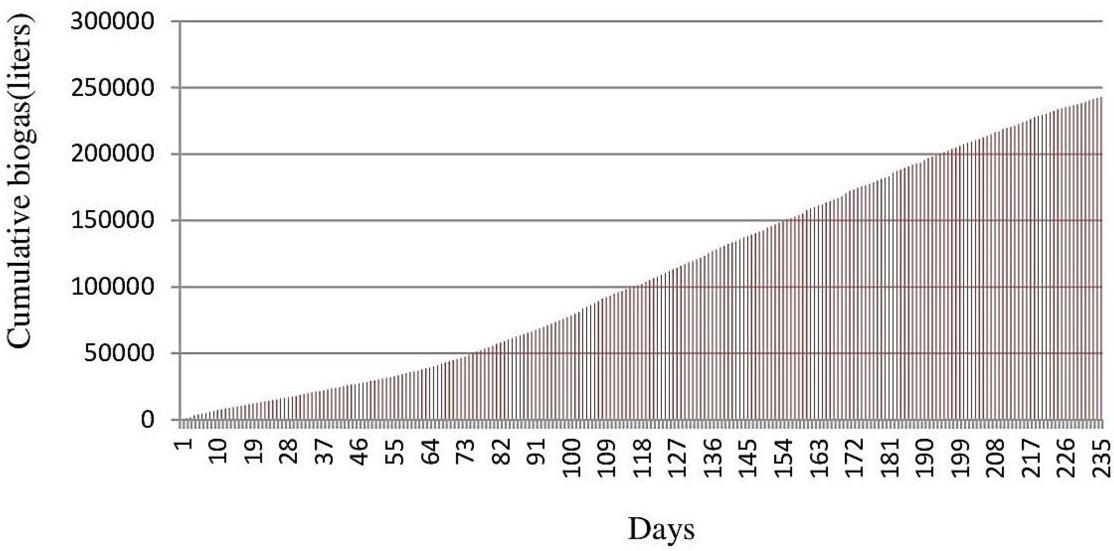

Figure 10 Cumulative biogas output from HomeBiogas7.0 systems

Table 4 Average gas production and cooking hours

SN	System	Family members	Gas used per person per day (m^3)	Total hours cooked	Gas used per day (m^3)	Average hours of cooking per day
1	S_1	3	0.293	1170.36	0.878	3.25
2	S_2	4	0.171	912.57	0.684	2.53
3	S_3	4	0.197	1048.53	0.786	2.91
4	S_4	6	0.132	1059.93	0.795	2.94
5	S_5	8	0.125	1337.95	1.003	3.72
6	S_6	6	0.350	2796.72	2.098	7.77
7	S_7	4	0.105	560.19	0.420	1.56
8	S_8	7	0.146	1365.19	1.024	3.79
Average		5	0.189	1281.43	0.961	3.56

3.2 Seasonal variation of gas production

The average yearly temperature of this region was 24.79 °C. It was 20.12 °C in the winter, 25.69 °C in the spring, and 28.59 °C in the rainy season with seasonal variation. The gas output in the winter season (27/Dec/2019 to 13/March/2020) was 0.638 m^3/day, 1.093 m^3/day in the spring season (17/March/2020 to 31/May/2020) and 1.158 m^3/day in the rainy season (30/June/2020 to 19/August/2020). There was diminished biogas production of 6.41% from the rainy to the spring season, and a sharp 41.61% reduction from spring to winter. Figure 11 shows the seasonal variation in gas production. When the digester temperature was reduced from 35 °C - 20 °C, biogas production decreased. There was a smaller drop in biogas production as temperature was reduced from 30 °C to 25 °C, but a much larger drop when it was reduced from 25 °C to 20 °C. Additionally, the methane concentration in the biogas varied with temperature fluctuations [36].

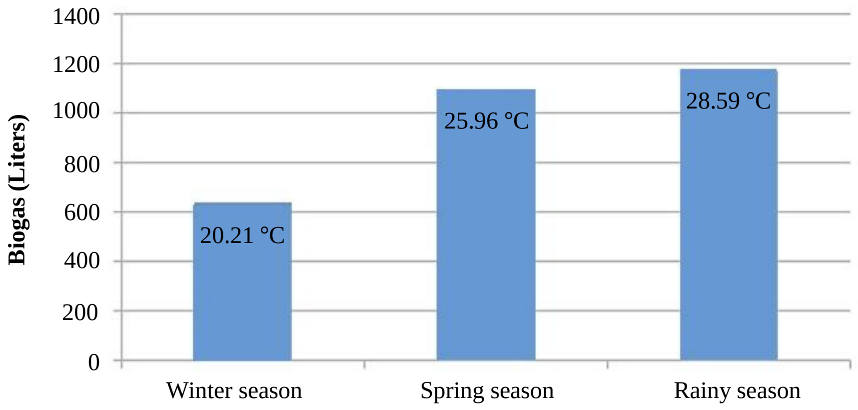

Figure 11 Seasonal biogas output from a HomeBiogas7.0 system

3.3 Biogas composition and LPG substitution

The composition of the produced gas was determined using a gas flow analyzer (Geotech Biogas 5000 portable biogas analyzer). A HomeBiogas7.0 system can replace 13.4 kg of LPG/month. The details of biogas concentration of each system are shown in below Table 5 along with mean values and standard deviations from eight research systems. The concentration of CH_4 was 56.1%, CO_2 was 40.4%, O_2 was 0.4%, NH_3 was 54.9 ppm, CO was 3.4 ppm and H_2S was 59.6 ppm. The concentration of methane gas in the biogas was 40-60% [37]. Biogas produced by anaerobic digestion (using animal manure) consists of methane (60%), CO_2 (40 %), and other gases in trace amounts [38]. Biogas produced from co-digestion of cow manure and water hyacinth produces a gas that is 56.4% CH_4, 35% CO_2, and 6.9% N_2, with other gases in trace amounts [39].

Table 5 Biogas composition from a HomeBiogas7.0 system

SN	Gas	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	Mean	Standard deviation
1	CH_4 (%)	56.4	58.1	53.7	55.8	56.1	55.4	54.8	58.1	56.1	1.52
2	CO_2 (%)	40	37.1	40.4	40.7	40.7	42.2	41.6	40.8	40.4	1.51
3	O_2 (%)	0.4	0.3	0.5	0.3	0.3	0.2	0.5	0.6	0.4	0.14
4	NH_3 ppm)	8	28	303	16	6	10	28	40	54.9	100.95
5	CO (ppm)	2	0	3	3	1	5	8	2	3.4	2.37
6	H_2S(ppm)	7	40	359	14	6	15	16	20	59.6	121.42

3.4 HomeBiogas vs GGC-2047 model biogas plants

A fixed dome biogas plant (GGC-2047 model) is a permanently installed biogas plant that can be constructed using locally available materials. It can range in size from 2 m^3-100 m^3 or sometimes even larger. A comparison of HomeBiogas and GGC 2047 system biogas plants is given in Table 6.

Table 6 Comparison of HomeBiogas and GGC-2047 model biogas plants

S. No		HomeBiogas model	GGC-2047 model
1	Material	A HomeBiogas system is constructed of the following: Outer cover is made of high-quality polypropylene sheets laminated with polyethylene for both UV protection and strength meeting the highest standards. Density of material is optimal for strength and flexibility. A gas liner is made from multi-layer polyethylene and aluminum for optimal strength and minimal OTR (oxygen transmission rate). Manufactured using a fully automated manufacturing process, highest QA standards. A digester liner is made from advanced polyethylene co-extruded barrier cover film for optimal OTR, strength and flexibility.	GGC-2047 is generally constructed of stone/bricks, rods, concrete, sand and cement.
2	System Structure	The gas-holding chamber and digester are separate. Gas flows from digester to gasholder through a gas filter. Clean gas is stored in the gasholder and supplied to kitchen through a pipe. As digester and gasholder are completely separated and are operated in parallel, the slurry cannot get into the gas pipeline.	The gas-holding chamber and digester are interconnected. In the case of gas overuse or a gas leakage in the dome, slurry may flow into the gas pipeline.
3	Stove	The stove is automatic and manual (ignition), compatible with the system pressure.	The stoves are individual (in the case of family using double stoves), compatible with the system pressure, and are not automatic (need separate ignition).
4	Gas Filter	A gas filter cleans sulfides from the biogas.	No gas filter.
5	Installation	It is installed on the surface of the ground. A 7 m^3 system needs around 2.7 m x 5.2 m of space for the total system installation. No excavation work is required. No need of masonry work or any removal of soil except for proper surface layout (flattening the surface) which needs to prepare before installation.	It is installed below the surface of the ground. A 6 m^3 system needs around 3 m x 6 m of space for the total system installation. Excavation needed. Sometimes it becomes difficult to install, particularly in hilly areas where the excavation may encounter large stones. Soil has to be removed for system construction and needs to be replaced for dome construction as well as removed again to bring the system into operation.
6	Installation time	<6 hours	20-30 days
7	Feeding Material	Cow dung/kitchen waste/human waste	Cow dung/human waste
8	Durability	15+ years	15+ years
9	Mobility	The system can be moved after installation if done with care and in the proper way. The portable system comes in a box with all of its components, pipe fittings, and a stove. It can easily be transported to locations where there is no road access. The weight of the unassembled system is less than one bag of cement.	The system, once installed, is stationary. It cannot be moved. It is a fixed (not portable) system. Bricks/stones, cement, sand, rods, aggregates need to be transported to construct the system. It is difficult and costly to transport all the materials when there is no road access.
10	Gas Production	Gas production is maximal in summer season and decreases in winter season.	Gas production is maximal in summer season and decreases in winter season.
11	Gas usage (experience of users)	Summer: >4 h (Average) Winter:>2 h (Average) Ref. 7 m^3	Summer: >4 h (Average) Winter:>2 h (Average) Ref. 6 m^3
12	Gas Production (liters)	0.961 m^3/day with 33±12 kg input of animal manure at 24.79 °C ambient temperature for the HomeBiogas7.0 system. 0.201 m^3/day with an organic loading rate per day of 0.475 kg VS/m^3 at an ambient temperature of 13.84 °C for a 2 m^3 HomeBiogas system [40].	0.452 m^3/day with 40 kg input of animal manure at an ambient temperature of 18.75 °C for a 6 m^3 GGC-2047 system [41].
13	Gas Pressure	1-1.5 kilopascals An even pressure is spread on top of the gasholder (by sandbags) forcing the gas into the kitchen for immediate use.	5-15 kilopascals The gas reaches to kitchen as a result of slurry pressure at the outlet.

Table 6 (continued) Comparison of HomeBiogas and GGC-2047 model biogas plants

S. No		HomeBiogas model	GGC-2047 model
14	Gas volume determination	The volume of gas stored can be visually determined, thus assuring the users of gas availability.	Exact volume of available gas cannot be known by the user.
15	Human Resources	General labor with basic installation skills and experience with layout measurements can easily install the system. Therefore, it requires less time to train the technicians. Training time: 3 days Number of skilled technicians: 1 man-day. Number of unskilled workers: 2 man-day. Per installation, Ref. 7 m^3 system.	Labor with masonry skills as well as experience in design measurements is required. Therefore, this takes more time to bring laborers to a full skill level. Training time: 6-7 days Number of skilled technicians: 5-6 man-day. Number of unskilled workers: 15-20 man-day. Per installation, Ref. 6 m^3 system.
16	Recyclability	System components are recyclable.	Some of the materials are recyclable.
17	Repair and maintenance	As the system is installed above ground, a fence is recommended. When repairs are needed, it is accessible and work can be done easily.	Most of the system is installed underground. When repairs are needed, it is difficult to identify the exact damage. Thus, repairs may be complicated.
18	Resilience	Natural calamities like earthquakes are less likely to damage the system.	In case of an earthquake, the probability of system damage is high.
19	Safety	It is completely safe during the installation and cleaning of the system.	There is danger of injury during installation or system cleaning.
20	Cost	The cost of the system is lower than a fixed dome (GGC-2047) of a similar size. Less chance of increases in system costs.	The cost of the system is higher than the HomeBiogas system. The system cost has markedly increased and will continue to increase as the cost of sand, brick, stone, cement, aggregate have been increasing.
21	Installation Rate and Employment	A larger number of systems can be installed in a given time period. This enhances employment opportunities, and helps developing the local economy.	Lower number of systems can be installed in a given time period.
22	Women empowerment	Women can become installers, supervisors, technicians, and gain confidence to become company owners.	Installation primarily requires masonry work. Therefore, there are fewer women involved as installers and technicians.

4. Conclusions

The HomeBiogas system provides much greater benefits than traditional biogas technology, but requires safety measures to protect it from damage. Additionally, it requires careful site selection/location. This system provides a sufficient amount of biogas for cooking, both in the summer and winter seasons when the biogas generator feed rate is sufficient. Women can be empowered as sales persons, supervisors, and technicians.

System design is simpler. There is no chance for slurry to enter the gas pipeline. There can be a large number of installations in a short time that are resistant to natural calamities like earthquakes. The system has fewer parts that require maintenance and it is portable. The average number of people in a family in rural and semi-rural Nepal is five. From family to family, there is variation in gas consumption and cooking time. Gas use per person ranges from 0.105-0.293 m^3 and total cooking time was 560.19-2796.72 hours/family during 360 days. The biogas produced from the HomeBiogas7.0 was 0.961 m^3 per day with 33±12 kg/day animal manure input. The ambient temperature was 24.79 °C and energy produced from the system was 5.766 kWh/day. The HomeBiogas7.0 system can replace 13.4 kg of LPG/month. One kg of animal manure yields 29 liters of biogas. There is seasonal variation in biogas production. Operation in the winter season yields 638 liters/day, while the spring season yields 1093 liters/day, and the rainy season yields 1158 liters/day. There was a sharp 41.61% drop in biogas production from the spring to winter season. Temperature profile of the area shows that the HomeBiogas7.0 system can be installed in the study area.

The concentration of CH_4 is 56.1%, CO_2 is 40.4%, O_2 is 0.4%, NH_3 is 54.9 ppm, CO is 3.4 ppm and H_2S is 59.6 ppm in the biogas. This technology can be widely distributed among users to meet their energy demands in rural areas so people have to rely less upon traditional sources of energy (firewood, dung cake, coal, and agricultural residues). Fewer repairs and less maintenance are required, so this system is more reliable than other technologies. The HomeBiogas system is a green technology that will benefit the developing world, upgrade its bio-economy and promote a circular economy. Further research needs to address economic analyses, reduction of TS and VS, yearly variations of biogas production, and solids accumulation with long-term digester use.

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