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Experimental Study of Design and Implementation of Small-Scale Biogas Digest System

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Abstract

The main purpose of this study is to design and implement a small-scale biogas digest system, which can provide a certain amount of natural gas (N.G.). The percentage of methane gases emissions according to the various research studies is around 25% of the total emission gases of the waste materials. For all industrialized nations, food waste costs approximately $680 billion/year. The dramatic increase in population and the waste of organic and non-organic materials lead to the use of biomass energy as the source of the renewable energy system to produce a natural gas (N.G.), which can be utilized in cooking or commercialized for the public. The burn out of the waste and the garbage materials causes tremendous pollution and global warming; however, utilizing the Biogas Digest System (BDS) will stop polluting the surrounding environment. The amount of natural gases production was measured for various atmospheric conditions. The important findings of this study are the amount of N.G., which can be increased by mixing two different types of organic waste materials.

Keywords

Biogas, Digest, Organics, Fertilizing, Biomass Energy, System

1. Introduction

Biogas production from organic waste may play an important part in improving our environment and economy. Organic waste should not be seen as a source of environmental pollution that has to be gotten rid of by putting it in landfills or burned in incinerators, as this could cause other pollution problems.

Organic waste is a material that is biodegradable and comes from either a plant (daily foods waste) or an animal (dung). The organic waste is usually broken down by other organisms (chemical reactions) over time and may be referred to as wet waste. Most of the time, it is made up of vegetable and fruit debris, paper, bones, and human waste which quickly disintegrate [1]. In many applications, the natural gas that produced from the Biogas Digest System can be utilized in either cooking or producing electricity by running a simple Rankine power plant. Saudi Arabia is one of the five most energy-consuming countries in the world. The electricity consumption is 24,400 kilowatt-hours a year in the Kingdom, more than five times the consumption in France and Germany, and twice as much in Norway, Canada, and the United States [2]. Although we know that, the weather in the Kingdom is one of the main reasons for the rise in consumption. There are some practices that led to large inflation of consumption, such as the absence of thermal insulation of 70% of buildings, the absence of use of energy-saving lamps, leaving the lighting and air conditioning working when we leave our houses [3]; therefore, the waste materials can be implemented as another source of electricity/or N.G.

In this study, the researchers proposed a flexible, compact, and durable design of the Biogas Digest System in order to be utilized to convert the huge amount of the waste foods or any organics materials to either a natural cooking gas or fertilizing materials. Moreover, the waste material can be converted to commercial electricity. Biomass in the Kingdom of Saudi Arabia has increased rapidly in a few years due to the expansion of new industries, as shown in **Figure 1**. Biomass energy is a source of renewable energy that can be produced from industries' raw materials, household waste, etc. Generally, the large amount of waste is generated mainly from municipal solid waste, and the estimated total biomass energy potential in Saudi Arabia is 3.0 (mtoe) (15% of 20.25 Million Ton in Arab Countries) [4]. Saudi Arabia is ranked the fourth among Arab countries that produced a huge amount of Biomass energy potential after Morocco, Egypt, and Sudan, as shown in **Figure 1**. The mechanism of the Biogas digest system (BDS) is similar to the digestive system of the human being; the digestive system is called the gastrointestinal tract/or the GI tract. All the organic materials are converted to energy in a body after the chemical reaction is completed. Each part of your digestive system works to move food and liquid through your GI tract, break food and liquid into smaller parts, or both. Once foods are broken into small enough parts, your body can absorb and move the nutrients to where they are needed. Your large intestine absorbs water, and the waste products of digestion become stool. Nerves and hormones help control the digestive process, as shown in **Figure 2**.

Biogas is generated by microscopic organisms by transforming bio-degradation of natural materials under anaerobic conditions which is the chemical process with the absence of oxygen. Biogas plants have increased rapidly in Europe between 2009 and 2015. They produced approximately 6000 to nearly 17,000 MW [5]. Biogas production is mainly three stages biochemical process: Hydrolysis, Acidogenesis/acetogenesis, and Methanogenesis, as shown in **Table 1** [6].

Table 1. Biochemical process.

Name of the Biochemical Process	*Chemical Formula*
Hydroulysis	$(C_6H_{10}O_5)_n + nH_2O \rightarrow n(CH_{12}O_6)$
Acetogenesis or Acidogenesis	$n(C_6H_{12}O_6) \rightarrow nCH_3COOH$
Methanogenesis	$nCH_3COOH \rightarrow nCH_4 + CO_2$

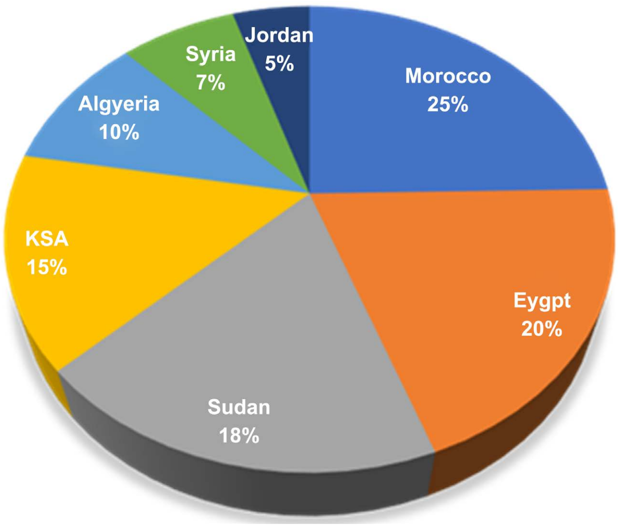

Figure 1. Biomass energy potential in 7 Arab countries.

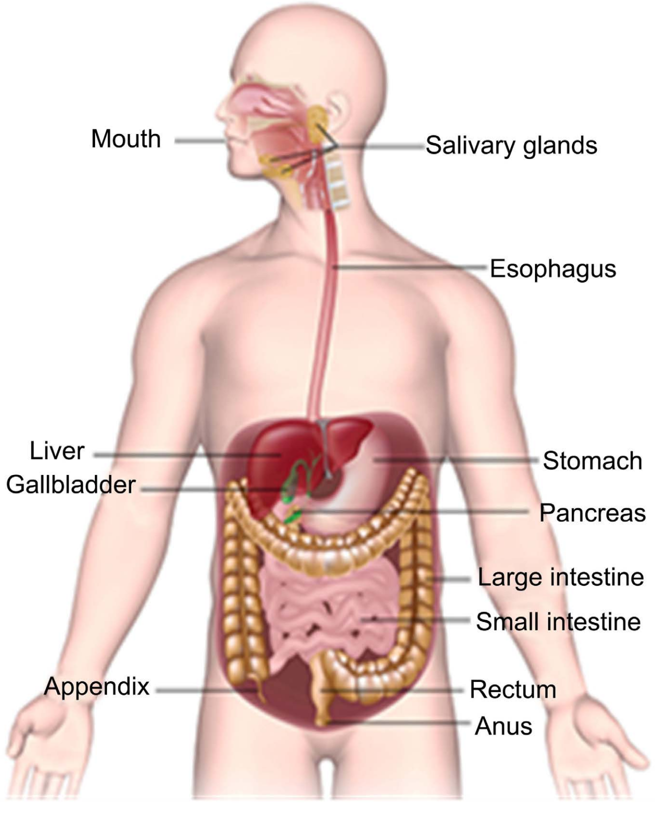

Figure 2. Digestive system in a human body.

Biogas (it consists of CH_4 and CO_2) can be transferred to bio-methane in two steps: 1) A cleaning process to remove the trace components (water vapor, hydrogen, sulfide, siloxanes, hydrocarbons, amonia, and 2) an upgrading process to adjust the calorific value [7]. **Figure 5** shows the amount of waste materials in the Hajj for four years. The amount of waste materials in KSA is around 16 MT/year (50% is organic materials, 15% is plastic materials, and 35% is solid waste materials) [1].

The design and manufacturing of biodigesters usually need skilled expertise, making installation expensive and time-consuming, especially for rural areas [8] [9] [10] [11]. In the meanwhile, many plants in the world built by the government are using crude oil, which causes a lot of pollution and a rise in global temperature [12] [13] [14]. Therefore, producing natural gas from the biomaterial using a biogas digest system could be an alternative solution for reducing global warming [15].

The anaerobic digesting process is a process of converting an organic material with the absence of oxygen, as shown in **Figure 3**. An anaerobic organism is any organism that does not require oxygen for growth [16]. The numerical/CFD investigation had been studied for a small-scale biogas digest system [17].

The foods, bottles, woods, and others waster are biomass potential energy. Also, the biomass potential energy can be wasted from farming (like wheat stalks) or horticulture (yard waste), food processing (like corn cobs), animal farming (manure), or human waste from sewage plants. The biogas reduces the huge amount of greenhouse gases emission to the environment; the environmental performance indicator of KSA (EPI) in 2018 is 86out of 180, as shown in **Table 2**. **Figure 4** shows the Hajj waster materials in Kingdom of Saudi Arabia for 5 days of Hajj period.

2. Methodology and Experimental Setup

The design, as shown in **Figure 5**, consists of two main tanks: the digestive tank

Table 2. Environmental performance index [8].

EPI Ranking [8]	EPI	EH	Ecosystem Vitality
86	57.47	72.81	47.25

EPI: Environmental Performance Index; **EH:** Environmental Health. The score of EPI means: 0 is the worst and 100 is the best.

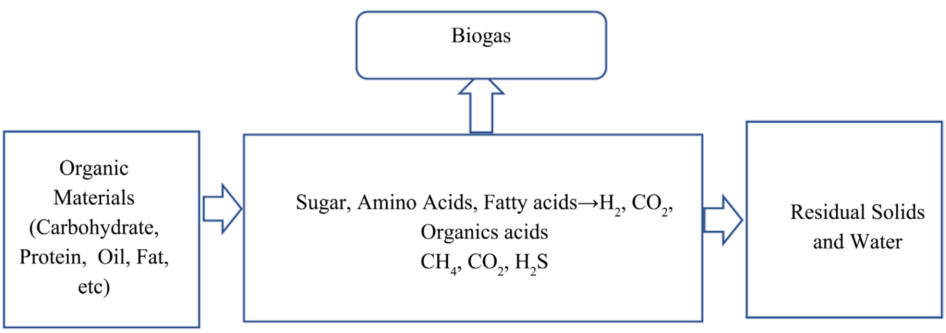

Figure 3. Anaerobic digester.

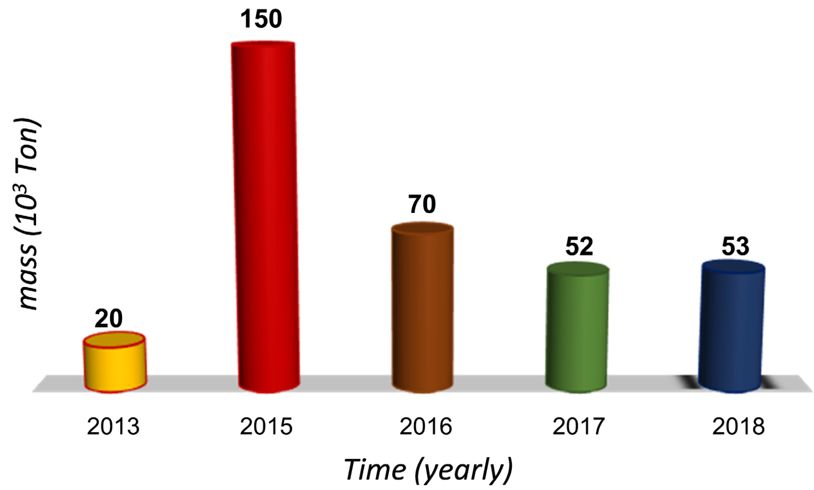

Figure 4. Hajj's waste (organics and non-organics waste) for 5 days only (period of Hajj).

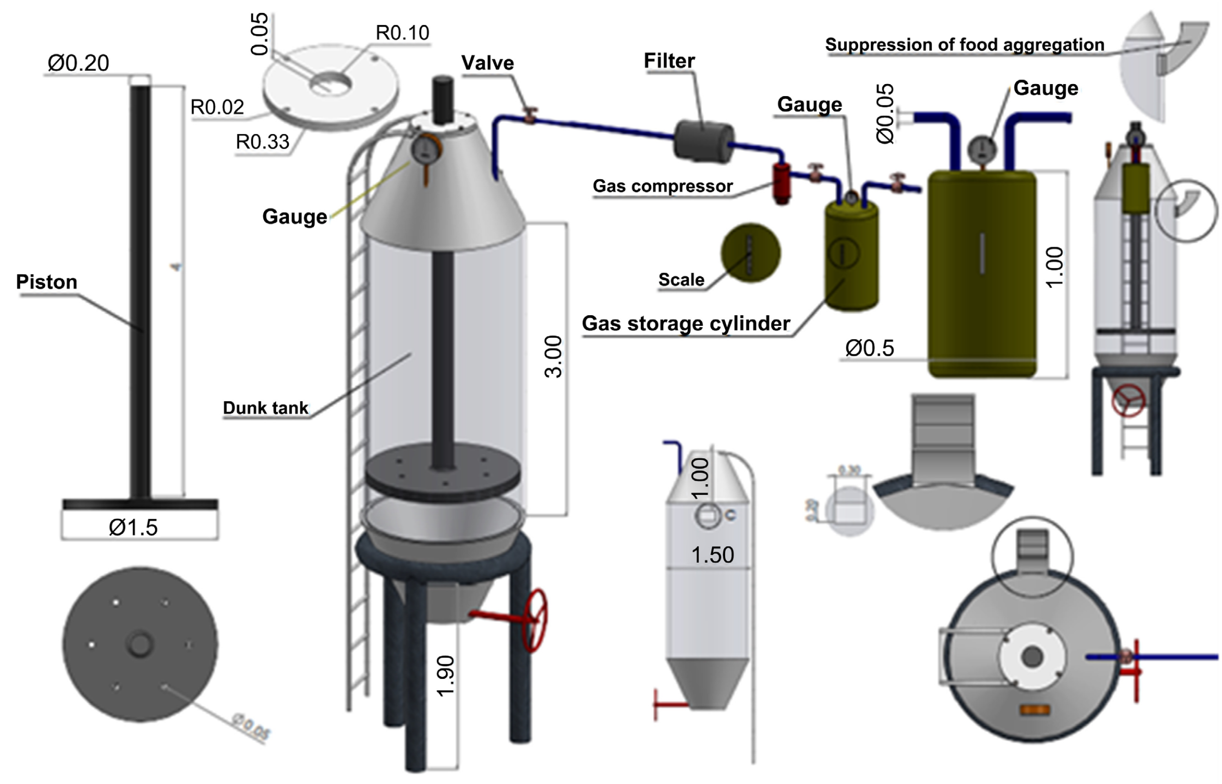

Figure 5. Biogas and bio-methane digest system.

(cylinder) and the storage tank (cylinder). The dimension of the Biogas Digest System (BDS) is based on the required biomass energy. The two tanks are connected by the main biogas stream line. The coal filter is placed on the main stream line to remove the bad smile of the biogas. Three-gauge pressure meter are placed on each cylinder in order to measure the gas pressure inside each tank. The organic materials mix with a little water inside the waste tank; the organic materials in the waste tank are compressed using a compression piston in order to release and produce more gases. After gases are released, the remaining waste materials can be used as a fertilizing material. During this process of gas production, the main stream line valve has to be opened. The valve underneath the waste tank is used to remove the reaming organics materials after the decomposition process; so, the fertilizing materials will be drawn from the bottom of the waste tank easily. The waste tank is an un-insulated tank which can absorb more heat from the surrounding.

3. Results and Discussions

As known, the calorific value of methane = 55 × 0.668 = 36.74 MJ/m^3. Methane being the only major source of heat, calorific value of biogas = 0.6× 36.74 MJ/m^3 = 22.044 MJ/m^3. The prototype Biogas Digest System of 1 m^3 capacity produces 0.7 m^3 of gas per day. Net energy in 0.7 m^3 of biogas = 0.7 × 22 MJ. Net energy in 0.7 m^3 of biogas = 15.4 MJ. Consequently, the energy provided per two weeks is =15.4 × 14 = 215.6 MJ. The designed digestive tank was fabricated to have a 1-m^3 capacity of dung, which produces around 215.6 MJ. Our suggested design can be scaled up, as shown in **Figure 5**. The digester tank and storage gas cylinder are the main important parts of this system. The coal filter was fitted on the main N.G. line to clean the N.G. gas from a bad smell. The compressor was placed after the filter to compress the N.G. and push it inside the storage gas.

The investigators designed a small-scale mechanical Biogas and Bio-Methane Digest System. The distinct cases had been investigated, which were taken at the ambient temperature range of 22˚C to 30˚C and influent temperature range of 32˚C to 39˚C within a retention period of 13 weeks. The daily biogas production was graphically presented in **Figure 6**. Case (1): A 60 kg of wet dung was mixed uniformly in batches of 10 kg in 10 liters of water to create a consistent mixture. Case (2): the foods (fruit/vegetables, Rice, and Bread) were studied separately with the same quantity of wet dung. The results were measured and calculated, as shown in **Table 3**, for 13 weeks. The calculations were taken based on the ideal gas equation at NTP as well as at various temperatures, as shown in **Figure 6**. The surrounding temperature has a crucial effect on the materials inside the storage tank and helps the bacteria to decompose the materials quickly, as shown in **Figure 7**. Consequently, the amount of gas production was increasing if the organic materials decomposed completely. Also, it was directly proportional with the increase of the average temperature, as shown in **Figure 8**.

Figure 9 shows the Accu weather temperature distributions were taken for four months in Almadinah Almunwwarah, KSA from the 1st of June to the 30th of September, 2020. The temperature has a strong effect on the decomposition of the organic materials inside the biogas digest system. The organic materials and non-organic materials can be recycled and reproduced as natural gas for cooking or fertilizing materials for farms. The small-scale biogas digest system in this study might be used at home.

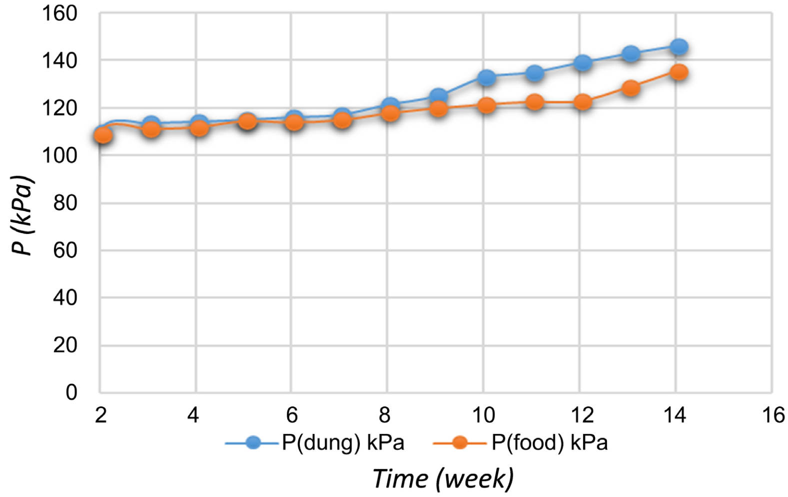

Figure 6. The pressure of gases inside the digester cylinder.

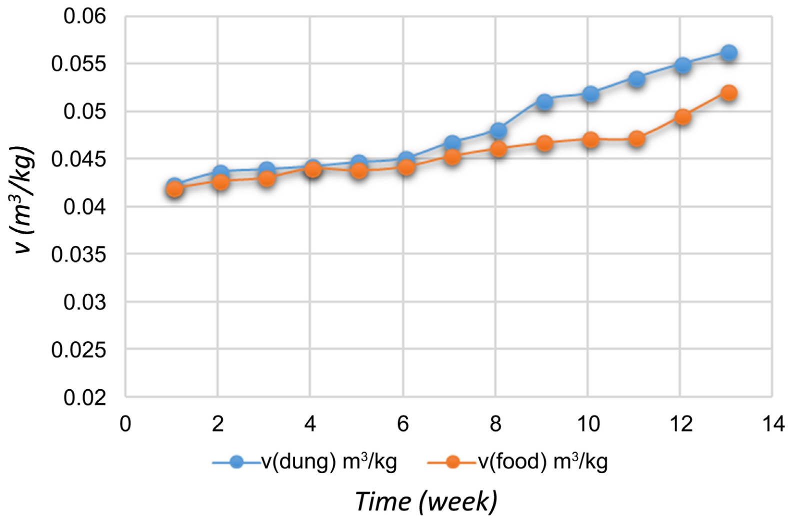

Figure 7. The amount of producing gas for dungs and foods.

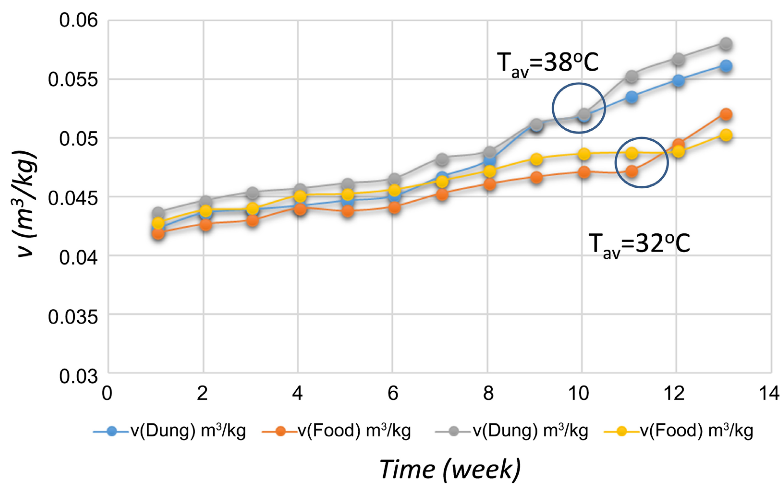

Figure 8. The amount of producing gas for dung and foods at surrounding temperature T = 30˚C - 35˚C and T = 35˚C - 40˚C.

Table 3. Measured and calculated experimental data (from 1st of June to 1st week of September, 2020): Location: Almadinah Amunwwarah, KSA).

Weeks No.	P (Foods) kPa	P (Dung) kPa	v (Foods) m^3/kg	v (Dung) m^3/kg
1	107.8	110	0.042792348	0.043666
2	110.5	112.5	0.043864141	0.044658
3	110.9	114.3	0.044022925	0.045373
4	113.6	115.1	0.045094719	0.04569
5	113.98	116.23	0.045245564	0.046139
6	114.89	117.23	0.045606798	0.046536
7	116.78	121.5	0.046357053	0.048231
8	118.9	123.08	0.04719861	0.048858
9	121.5	128.99	0.048230707	0.051204
10	122.6	131.08	0.048667364	0.052034
11	122.9	139.2	0.048786452	0.055257
12	123.1	142.98	0.048865844	0.056757
13	126.7	146.23	0.050294902	0.058048

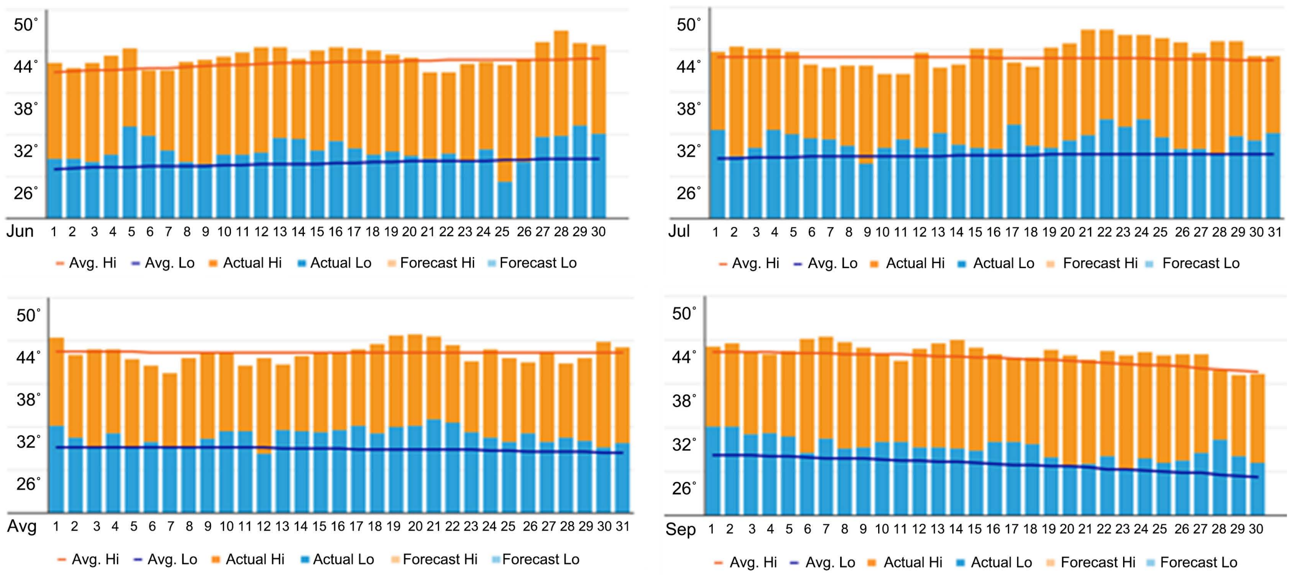

Figure 9. Temperature profile from 1st of June to 30th of September, 2020 at Almadinah Almunwwarah.

4. Conclusions

In this study, the new biogas and Bio-Methane Digest System (BDS) was designed. The two cases were investigated for dung and food waste. The study found that the wet dung produces a large amount of N.G. than the food waste placed in the same surrounding conditions. With a large-scale digest system, the amount of biogas production will be more and it can be utilized for commercial purposes. The large amount of N.G. at the average surrounding temperature T_{av} = 38˚C of organics waste/or biomaterials will produce a huge amount of N.G.

(≥60% of CH_4 of the total waste materials gases).

The study noticed that dung or food waste are a good substitute for L.P.G, and the methane gases production might be used on a commercial basis, which is safer and keeps the environment clean. There is more than 60K tons of garbage burned every year, which causes tremendous pollution in one city in KSA, as an example. Also, the study found that mixing more than one type of food together produced more natural gases because the mixing materials decomposed quickly. The type of organic materials and the surrounding temperature play a significant effect on producing biomass energy.

Availability of Data and Materials

Availability of data and materials Data sharing requested from the correspondence author of this article.

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Authors' Contributions

The authors designed, studied, and analyzed equally the effect of type of organic materials and surrounding temperature on the amount of natural biogas production.

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Conflicts of Interest

The authors declare that they have no competing interests.

References

[1] Khan, Md.S.M. and Kaneesamkandi, Z. (2013) Biodegradable Waste to Biogas: Renewable Energy Option for the Kingdom of Saudi Arabia. *International Journal of Innovation and Applied Studies*, **4**, 101-113.

[2] Svensk, F. (2001) Förordning (2001:512) om Deponering av Avfall. (In Swedish). https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/%20forordning-2001512-om-deponering-av-avfall_sfs-2001-512

[3] Ghimire, P.C. (2013) SNV Supported Domestic Biogas Program in Asia and Africa. *Renewable Energy*, **49**, 90-94. https://doi.org/10.1016/j.renene.2012.01.058

[4] Zhang, L. and Wang, C. (2014) Energy and GHG Analysis of Rural Household Biogas Systems in China. *Energies*, **7**, 767-784. https://doi.org/10.3390/en7020767

[5] Singh, P., Singh, P. and Gundimeda, H. (2014) Energy and Environmental Benefits of Family Biogas Plants in India. *International Journal of Energy Technology and Policy*, **10**, 235-264. https://doi.org/10.1504/IJETP.2014.066881

[6] Haimi, J., Lensu, A., Marjomäki, T. and Marjomäki, V. (2014) Biogas Production from Meat, Pulp and Paper Industry by Products. Jyväskylä Studies in Biological and Environmental Science, Jyväskylä University.

[7] Ryckeboscha, E., Drouillonb, M. and Vervaerenc, H. (2011) Techniques for Transformation of Biogas to Biomethane. *Biomas and Bioenergy*, **35**, 1633-1645. https://doi.org/10.1016/j.biombioe.2011.02.033

[8] Environmental Performance Index (2021) https://saudigazette.com.sa/article/607423

[9] Amare, Z.Y. (2015) The Benefits of the Use of Biogas Energy in Rural Areas in Ethiopia: A Case Study from the Amhara National Regional State, Fogera District. *African Journal of Environmental Science and Technology*, **9**, 332-345. https://doi.org/10.5897/AJEST2014.1838

[10] Angelidaki, I. (2004) Environmental Biotechnology. AD: Biogas Production. Environment and Resources, DTU, 23-28.

[11] Blum, N.U., Wakeling, R.S. and Schmidt, T.S. (2013) Rural Electrification through Village Grids—Assessing the Cost Competitiveness of Isolated Renewable Energy Technologies in Indonesia. *Renewable and Sustainable Energy Reviews*, **22**, 482-496. https://doi.org/10.1016/j.rser.2013.01.049

[12] Breiland, G. (2013) Bridging the Gap between Prototypes and Production. https://www.mdtmag.com/article/2013/11/bridging-gap-between-prototypes-and-production

[13] Subbarao, C., Bhale, P.V., Reddy, S.N. and Mouli, Ch.C. (2013) Laboratory Scale Experiments for Biogas Production Using Gas Chromatography Analysis. *IOSR Journal of Engineering*, **3**, 4-7. https://doi.org/10.9790/3021-03730407

[14] Damuri, Y.R. (2011) Pricing Practices in Indonesia's Electricity Power Services. Centre for Strategic and International Studies (CSIS), 5-12.

[15] Deublein, D. and Steinhauser, A. (2010) Biogas from Waste and Renewable Resources: An Introduction. 2nd Edition, Wiley-VCH, Weinheim. https://doi.org/10.1002/9783527632794

[16] Al-Rousan, A. and Zyadin, A. (2014) A Technical Experiment on Biogas Production from Small-Scale Dairy Farm. *Journal of Sustainable Bioenergy Systems*, **4**, 10-18. https://doi.org/10.4236/jsbs.2014.41002

[17] Hasan, M., El-Shahat, A. and Rahman, M. (2017) Performance Investigation of Three Combined Airfoils Bladed Small Scale Horizontal Axis wind Turbine by BEM and CFD Analysis. *Journal of Power and Energy Engineering*, **5**, 14-27. https://doi.org/10.4236/jpee.2017.55002

List of Abbreviations

P: gas pressure in [kPa]; V: gas specific volume; LPG: Liquid Petroleum Gas; N.G: Natural Gas; T: Temperature in degree C; BDS: Biogas Digest System; NTP: Natural Temperature and Pressure; KSA: Kingdom of Saudi Arabia; AVG: Average; TaibahU: Taibah University; EPI: Environmental Performance Index; GI: Gastrointestinal Tract.