A Feasibility Study of Designing and Building a Solid-State Biogas Anaerobic Digestion System for Wastes Collected in the Month of Hajj

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Abstract

The statistics of the Holy Makkah Municipality demonstrated that the volume of waste reached to 11 thousand tons during only five days of the month of Hajj. The majority of these wastes are landfilled. These wastes decays in landfills and, without oxygen presence, emits methane, which is a more potent greenhouse gas than carbon dioxide. The proposed project is to convert food waste into gaseous fuels, solid fuels, biodiesel and other products. The process exploits microbiological metabolism under anaerobic conditions to yield high quality biogas in an environmentally safe and efficient manner. However, as shown by these techniques, the implementation process is complex. Therefore, the proposed study is specifically for Phase 1 of the project: feasibility analysis of a solid-state anaerobic digestion (SS-AD) system for food wastes generated during the month of Hajj. Feasibility Study will: provide technical information regarding the potential for the Umm Al-Qura University (UQU) to conserve energy, reduce energy costs, and lower greenhouse gas emissions through the transition from current food and yard waste management practices to SS-AD and provide information regarding potential options for implementation of SS-AD. It will contribute to the mission and vision of the UQU by enhancing educational opportunities for UQU students and faculty, fostering intellectual development among the students and researchers team, and providing potential for university-community collaborations. This project aims to enhance student and researcher success and institutional sustainability of the UQU through the implementation of a SS-AD system designed to valorize food waste generated on the holy sites (Mina and Arafat) during the month of Hajj. Successful completion of the project will improve the sustainability of UQU by providing an additional renewable energy source and offsetting greenhouse gas emissions associated with the energy footprint of current waste processing methods.

1. Introduction

While the Saudi Arabia has an notable natural potential for solar, wind and biomass power, the country still lack a competitive renewable energy sector at present. In addition, its local energy consumption will increase three fold by 2030. Thus, one of the important goals of the KSA's vison 2030 is to build up this sector. In this vision, an initial target of generating 9.5 gigawatts of renewable energy has been set [1]. Also, the KSA's government will also seek to localize a major portion of the renewable energy value chain in the Saudi economy, including research and development, and manufacturing, among other stages [1]. As a result, the future looks bright for all forms of bio-energy technology such as the production of biofuels. Also, it will be more and more used to meet the Kyoto

Protocol obligations and to profit from the CO_2-emission skill because it is a CO_2-neutral source of energy [2].
Anaerobic digestion (AD) is a bacterial fermentation process that operates without free oxygen and results in a biogas containing mostly methane and carbon dioxide. AD is also the principal decomposition process occurring in landfills. Biogas produced from AD has been promoted as a part of the solution to energy problems. Methane contains about 90% of the energy with a calorific value of 9000 kcal/m^3 (10.46 kWh/m^3) and can be burned on site to provide heat for digesters or to generate electricity. Little energy (3-5%) is wasted as heat in the biological process [2,3]. There are two basic types of AD technologies, 'wet' (low-solids) and 'dry' (high-solids). 'Dry' digestion is typically defined as having more than 15 percent of total solids (TS) inside the digester. The wet AD system commonly applies a continuous process flow, where dry AD systems apply either a continuous or batch process. In Europe, AD technologies to process source-separated organics (SSO) and organic fraction of municipal solid waste (OFMSW) on a commercial/industrial scale were developed more than 20 years ago. By the end of 2010, more than 200 AD plants treating SSO and OFMSW with a total installed capacity of about 6 million tons had been built. The trend is towards dry AD technology. Furthermore, fossil fuel consumption for transport should also be increasingly substituted by biomass to reach 8% by 2020 [4]. Spain reportedly sends the most waste to anaerobic digestion of all the EU countries. This has been precipitated in part by a directive by the Spanish parliament in August 2005 to increase renewable energy production from 19 percent of the total energy mix to 31 percent [4]. In Arab countries, the application of biogas plants started in 1970s in Egypt, Morocco, Sudan and Algeria while it began in 1980s in other Asian Arab countries as Iraq, Jordan and Yemen. In Egypt there were 18 family biogas plants and 2 farm plants built till 1998, also two family biogas plants were built in Keraeda and Um-Jar villages of Sudan. There were two constructed plants for producing biogas from liquid wastes in Jordan, one in Ain-Ghazal and the other in the central station of Irbid [5].

While Anaerobic Digestion of OFMSW is relatively well established in other nations, especially in Europe, it remains an undeveloped or developing technique in the Saudi Arabia. Future development of AD as a MSW management strategy depends on several parameters ranging from environmental concerns to economic considerations: increasing process efficiency, reducing digester operation costs, higher and more stable gas production. It seems that AD systems will continue to play a major role to decompose MSW organics in other nations while the application of AD on MSW is still to be determined in KSA. This process is still underutilizing because the system is not well known to the agricultural, industrial and engineering communities. Thus, the objectives of this study are to:

1. Demonstrate the effectiveness of the anaerobic digester as a cost effective means of waste minimization and energy production.

2. Describe and explain design criteria for optimal performance by comparison between dry and wet family AD.

3. Explain the benefits of anaerobic digestion of biomass for farmers, industry, and the municipality.

2. Pilot digesters

2.1 Experimental setup

Two pilot digesters (a self-mixing digester and a batch digester) were constructed in 1436 and 1437 H to be as prototype digesters for this study calculation on organic waste which can be used to design suitable digester for Makkah as a case study.

2.2 Digesters description

a) Vertical-mixing digester

The vertical-mixing digester consists of two isolating solar water heater drums each 120 liters capacity as show in Figure 1.

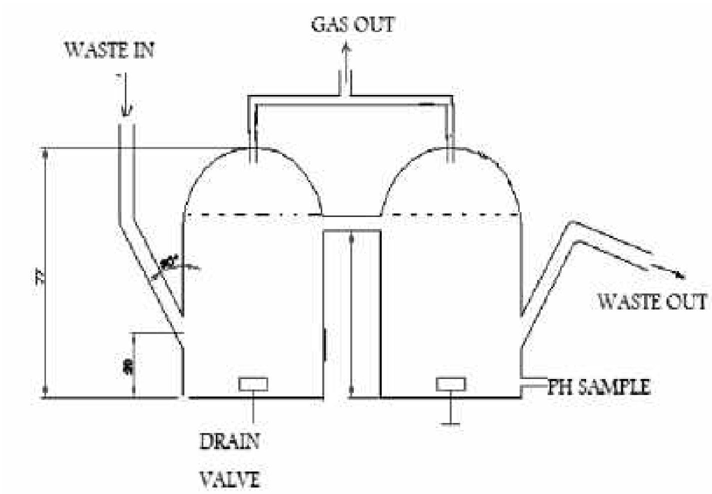

Figure 1. Vertical-mixing digester

The appropriate daily feeding amount is calculated as follows:
Vdigester = $t \times V_{feed}$ [10]
Vdigester = digester volume , V_{feed} = feed volume , t = retention time till the feeding stop assume it is 40 days, About 20% of digester volume as free space for gas, only 100 Liter out of 120 Liter each one was used for our calculation to keep 20 liter as free space for each drum.
Then; $V_{feed} = 1/40 \times V_{digester}$, if ($V_{digester}$ = 200 liter)
V_{feed} = 200 Liter/40 day = 5 L /DAY
We started by 60 liters mixed with manner waste to accelerate gas production and can made more consistent by continuously feeding the digester with small amounts of waste daily. The amount of dry waste 100 kg+100 liter of water was feeding at the end of 40 days.

b) Batch digester

The second type of digester is a Batch system as show in Figure 2. We started filling this digester by 40 kg of different types of organic waste (different types of vegetables, food waste, yard waste), and we used electric mixer to have completely homogenous liquid with 40 Liters of water.

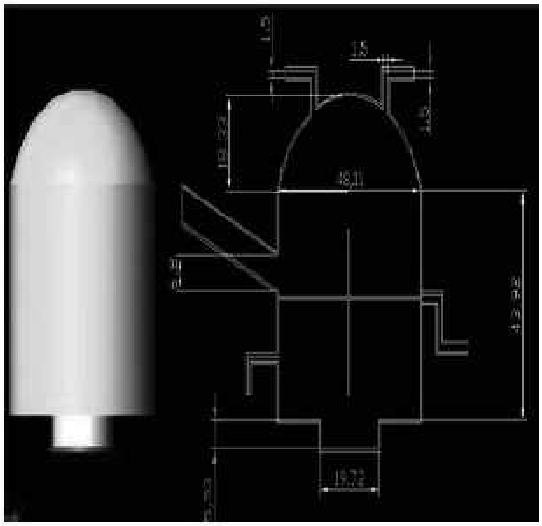

Figure 2. Batch digester

2.3 Experiment Results

The experiment started on 1/6/1437 H and finished on 10/7/1437 H, for 40 days. Table 1 and figures 3 and 4 below illustrate the measuring results of pH value and the amount of biogas produced.

Table 1. Ph and the amount of biogas produced for each digester

Day number	**Vertical-mixing digester**			**Batch digester**	
	Mix (L)	**Biogas (g)**	**pH**	**Biogas (g)**	**Ph**
1	60	0	11	11	0
2	5	0	10	10	45
3	5	25	8.5	8.5	95
4	5	55	8.2	8.2	105
5	5	75	8	8	135
6	5	90	7.6	7.6	140
7	5	110	7.5	7.5	170
8	5	125	7.2	7.2	170
9	5	160	7.1	7.1	175
10	5	205	7	7	180
11	5	245	7	7	180
12	5	310	7	7	195
13	5	315	7	7	195
14	5	315	7	7	210
15	5	320	7	7	215
16	5	340	7	7	220
17	5	360	6.9	6.9	220
18	5	370	6.8	6.8	225
19	5	380	6.7	6.7	230
20	5	385	6.7	6.7	235

21	5	395	6.8	6.8	235
22	5	415	6.8	6.8	230
23	5	435	6.9	6.9	215
24	5	455	7	7	215
25	5	465	7	7	210
26	5	425	7	7	210
27	5	395	7	7	200
28	5	380	7	7	190
29	5	375	7	7	190
30	5	370	7.5	7.5	185
31	5	365	7.8	7.8	180
32	5	355	8	8	170
33	5	350	8.5	8.5	165
34	5	335	8.5	8.5	155
35	5	330	8.5	8.5	140
36	5	325	8.3	8.3	125
37	5	320	8.1	8.1	115
38	5	315	7.8	7.8	100
39	5	310	7.8	7.8	85
40	5	300	7.8	7.8	45
Total biogas (g)		**11600**	**Total biogas (g)**	**6700**	

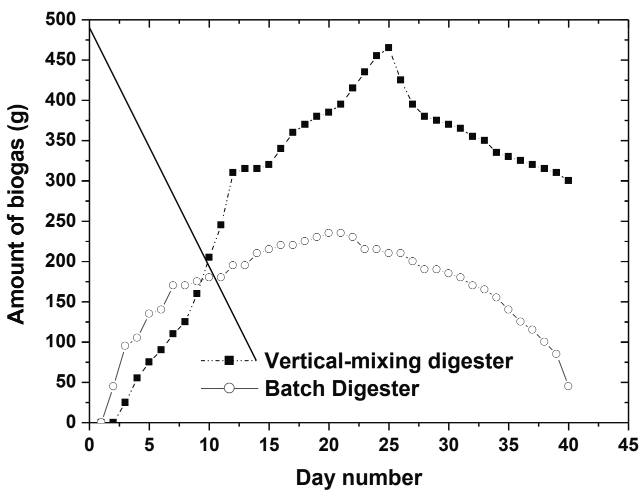

Figure 3. The amount of biogas for each digester

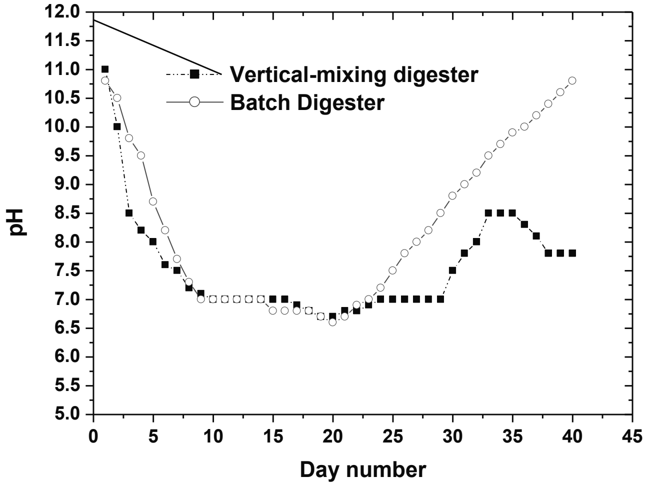

Figure 4. The pH value into each digester

For the vertical-mixing digester, the amount of biogas was produced =11.640 kg. Thus, the biogas in kg / kg dry waste = 11.600/100 =0.116 kg of bio gas /kg of waste. However, for batch digester, the amount of biogas was produced =6.700 kg. Thus, the biogas in kg / kg dry waste = 6.700/40 =0.167 kg of bio gas /kg of waste. In conclusion, the second type of digester is the best in producing biogas.

3. Case Study: Dry batch digester for waste amount in Makkah

3.1 Theoretical estimation of biogas amount in the Hajj month

Based on the amount of organic wastes received during the Hajj month in Makkah, the theoretical amounts of the production of biogas can be calculated. Yearly amount that considered as useful organic wastes was 51,869 tons out of total waste 86,449 tons [6]. This means that the estimated amounts of biogas production to be presented are achievable. Based on our experimentally work each one kg of organic waste can generates 0.16 kg of biogas. This amount is equivalent to 8,199,040 kg of biogas, or to 4,099,520 kg of butane gas as heating value. [Equivalents to 314,626 butane bottle/year (12 kg/bottle)]. With the cost of 16 SAR/bottle × 360,000 bottle = 5,466,016 SAR/Year.

3.2. Theoretical estimation of annual biogas production in Makkah

In 2013, the total waste in KSA is more than 12 million tons, where 40 % is produced from organic waste and 20% are from papers and cartons materials [7]. In 2015, the population of Makkah is around 1,578,722 [8]. The average waste produced is about 1.25 kg/day for each person [7]. Based on the amount of organic wastes which daily received to Makkah, the theoretical amounts of the production of biogas in Makkah can be calculated. Yearly amount that considered as useful organic wastes was 789,360 tons/year out of total waste 1,973,400 tons/year. This means that the estimated amounts of biogas production to be presented are achievable. Based on our experimentally study each one kg of organic waste can generates 0.16 kg of bio gas. This amount is equivalent to 126,297,600 kg of biogas, or to 63,148,800 kg of butane gas as heating value. [Equivalents to 5,262,400 butane bottle/ year (12 kg/bottle)]. With the cost of 16 SAR/bottle ×360,000 bottle = 84,198,400 SAR/Year.

3.3 The electrical power produced

Organic waste production rate =
Waste production (mass per capita/time) × population × organic fraction
=1.25×1,578,722×0.4
=789,361 kg/day organic waste **Eq. 1 [9]**

3.3.1 Organic Loading

With the rate of generation of organic waste per day and an assumed value of the Chemical Oxygen Demand (COD) of that waste (grams COD per kilogram of waste), a rate of organic loading into the digester from the solid waste must be calculated. Values for the chemical oxygen demand (COD) will be assumed in the range of 500 to 1000 g/kg [36]. We will use the value of 700 g/kg for our calculations.

Solid waste COD = organic waste (mass/time) × average COD
content (mass/mass)
= 789,361 kg/day × 700g/kg
=552,552,700 g/day
= 552,552 kg/day **Eq. 2 [9]**

3.3.2 Methane Production

Lettinga gives a figure of 0.25 g CH4 / g COD digested [10]. There are other factors that will affect the quantity of methane formed such as the quality and composition of organics in the waste as well as the type and number of microbes present [10].

Methane produced (mass/time) = COD digested (mass/time) × 0.25
= 552,552,700 g/day COD digested /day × 0.25 g CH_4
= 138,138,175 g/day = 138,138 kg/day of CH_4. **Eq. 3[10]**

If the Methane energy content: 34200 kJ/kg (9.5 kwh/kg biogas) [10], then 138,138 kg /day CH_4 × 9.5 kWh /kg = 1,312,312 kWh / day
We can produced as electrical energy = 1312.3 MWh/day.
With combustion engine efficiency 0.2, the electrical power produced is more than 10 MW (1312.3 MWh × 0.2 / 24=10.3 MW).

4 Conclusion

As with all forms of bio energy, the future looks bright for biogas technology. As a CO_2-neutral source of energy it will be increasingly used to meet the Kyoto Protocol commitments and to benefit from the CO_2 emission trade. Biogas is a flexible form of renewable energy that can produce heat, electricity and serve as a vehicle fuel. As well as energy, the AD process yields valuable fertilizer and reduces emissions and odor nuisances.

It will contribute to the mission and vision of the Umm Al-Qura University (UQU) by enhancing educational opportunities for UQU students and faculty, fostering intellectual development among the students and researchers team, and providing potential for university-community collaborations. This project aims to enhance student and researcher success and institutional sustainability of the Umm Al-Qura University through the implementation of a solid-state anaerobic digestion system designed to valorize food waste generated on the holy sites (Mina and Arafat) during the month of Hajj. Successful completion of the project will improve the sustainability of Umm Al-

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