Development and evaluation of household biogas plant with twin digesters in series

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HIGHLIGHTS
- Critical insight into Pakistan energy resources and potential available for biogas production
- Easy construction of biogas plant
- Comparison of biogas production with fresh material digester and slurry feeding digester

ABSTRACT

The study was conducted at PMAS-Arid Agriculture University Rawalpindi Pakistan to compare the biogas production from fresh material digester (FMD) and slurry feeding digester (SFD). The small biogas household plant was consisted of two digesters first Fresh Material Digester (FMD) and second Slurry Fed Digester (SFD) in series. The small size biogas plant was constructed with concrete rings available in the market instead of bricks and cement. The volume of each fermentation chamber is 9.2 m³ and the construction cost of this biogas plant is Rs. 50000. The household plant fulfills the cooking requirement of 3-4 family members. Three different treatments of feeding materials i.e buffalo dung (BD), buffalo dung plus sheep waste (BD+SW), buffalo dung plus chicken droppings (BD+CD) were studied. The highest biogas productions were recorded 0.46 m³/day, 0.51 m³/day and 0.50 m³/day from BD, BD+CD and BD+SW treatments, respectively in FMD. The highest biogas production in SFD was recorded 0.31 m³/day, 0.33 m³/day and 0.34 m³/day from BD, BD+CD and BD+SW treatments respectively. The SFD gave enough gas production that was 45% of the FMD. Thus by increasing the retention time of feeding doze in the construction of 2nd plant in series, the production of gas can be doubled.

Key words: Biogas, Anaerobic digestion, Fresh material digester, Slurry feeding digester, Biogas yield, Slurry temperature

1. Introduction

Energy plays a very important role in the progress and development of the country particularly in industrial and agricultural sectors. The existing energy resources are decreasing day by day due to excessive use, so the energy is becoming costly and
less available. Therefore, alternate energy resources are becoming important to explore in order to meet the rising energy demand of the developing countries.

The Pakistan household energy strategy study (HESS) undertaken in 2014 showed that biomass fuels account for about 86% of total household energy consumption, while wood fuel alone accounts for 54% of the total. The biomass is the major source of energy use for cooking and heating in Pakistan. Among the biomass wood, crop residues and animal dung are the major sources utilized for production of household energy. According to the Livestock survey during the year 2014, the total number of buffaloes and goats in Pakistan were 34.6 and 66.6 million, respectively. About three quarters of the billion tons of animal’s manure produced annually is burnt for heating or cooking.

Biogas technology is the production of methane rich gas and value added organic fertilizer through anaerobic digestion of farm yard manure, farm waste and other biomass. Thus Biogas is one of the important energy resources need to develop as an alternate source of energy to the rural community to cater energy demand and to reduce fossil fuel and wood consumption. (Yasin et al., 1996).

Biogas is a combustible gaseous mixture due to high percentage of methane. It is nontoxic in nature, has no aggressive smell, burns with clean blue flame, its calorific value is 650 BTU/ft³ (5735 K Cal/m³) and its thermal efficiency is 60%. Biogas is a mixture of different gases like methane (60-70%), carbon dioxide (30-40%), nitrogen (1%), hydrogen (0.1-0.5%) and carbon monoxide (0.1 %).

There are four basic types of microorganism which are responsible for the generation of biogas from agricultural waste and farmyard manure. First is the hydrolytic bacteria that breaks down complicated organic waste into amino acids and sugar. Second is the fermentative bacteria that convert amino acids and sugar into organic acids. Third is an acidogenic bacteria which converts the organic acids into acetic acid, carbon dioxide, hydrogen, and acetate. Finally, the methogenic bacteria produces biogas from acetic acid, carbon dioxide and hydrogen. (Ilaboya et al., 2010).

Yasin et al. (2011) studied three different treatment of feeding materials i.e buffalo dung, buffalo dung plus poultry litter and buffalo dung plus sheep waste at different feeding rates of 15, 30 and 40 kg/day respectively. The results showed that gas production 0.92, 0.82 and 0.79 m³/day, from BD+PL, BD and BD+SW at the level of 40 kg/day. The average slurry temperature was remained between 27-31°C. The pH value ranged from 7-7.2 was optimum for biogas production and pH value 7 gave the maximum biogas production (Ukpai et al., 2011), (Budiyono et al., 2013) and (Bani et al., 2014).

The slurry of fresh buffalo dung and water with the ratio of (50:50) was used. The biogas 121.5 ml/day was produced by slurry contained 200 g of buffalo dung and 200 g of water at an average temperature of 35°C. It was found that Biogas yield was increased with the increase in temperature, pH value and solid concentration (Ismat et al., 2004) and Ogiehore et al., 2014).

Dried chicken droppings 2.8 kg with 3.7 liter of warm water was added to anaerobic digestion at 28°C temperature. The biogas production was started after seven days with an average amount of 72.2 cm³/kg/day. Thus the chicken dropping could be used as feeding material for biogas production (Oyewale, 2010).

In Pakistan different biogas plants were installed but those biogas plants were larger in size and greater in cost. The construction and maintenance of those biogas plants were difficult and availability of huge quantity of dung was required. These biogas plants could not be dismantled to shift to another location and were not suitable to small farmers. To overcome these problems a low cost household biogas plant was designed and constructed to meet the energy demand of small families. The household biogas...
plant was designed and constructed to conduct this study.

1.1 Small biogas plant

The plant was consisted of two small size digesters first Fresh Material Digester (FMD) and second Slurry Fed Digester (SFD) as shown in figure No 3. The FMD was fed with fresh material and the SFD was fed automatically with slurry coming out of the FMD connected in series in order to extract gas left in the slurry. The small size biogas plant was constructed with concrete rings that are easily available in the market instead of bricks as used in the existing plants. Moreover the construction of this plant with concrete rings is easy and cheaper as compared to the other plants. The construction of biogas plant with bricks and cement is difficult, time consuming, costly and required more materials. The plants constructed with bricks are difficult to dismantle and move to other site whereas biogas plant made of concrete ring can be easily dismantled and moved to new site. The small biogas plant is more suitable to the small farmers having 2-3 animals because it requires less quantity of dung for initial filling as well as for daily feeding. This biogas plant is cheaper, easy to operate and simple to maintain. This small size plant is design to fulfill cooking requirement of a family having 3-4 members. The construction cost of this biogas plant is Rs 50000 and operational cost comes to Rs 46/h.

2. Materials and method

The study was conducted to test the performance of small size household biogas plant designed and constructed at Pir Mehr Ali Shah Arid Agriculture University Rawalpindi Pakistan. This study was planned to compare the performance of FMD and SFD in term of gas production, pH-value and fermentation temperature. The study duration was from December 2014 to June 2015. Three treatments Buffalo dung (BD), Buffalo Dung plus Chicken Droppings (BD+CD) and Buffalo Dung plus Sheep Wastes (BD+SW) with the treatment level of 50 kg/day were used. The treatment were mixed with water and fed to the digester. The treatments BD, BD+CD and BD+SW were mixed with water at the ratio of 1:1, 0.5:0.5:1 and 0.5:0.5:1, respectively. The data of gas production, pH value and slurry temperature for each treatment was recorded for 10 days. The data was analyzed using statistical complete Randomize Design (CRD). Analysis of the feeding material and slurry was performed to check the nutrients values and organic contents present in the feed and slurry coming out of the digester. The temperature, pH value and biogas production were measured with the help of thermometer, pH meter and gas flow meter, respectively on daily basis.

2.1 Construction and installation of small biogas plant

2.1.1 Fermentation chamber

The pit having size of 1.21 m deep and 1.82 m wide was made in the soil. The foundation of fermentation chamber was made with R.C.C to avoid breakage and leakage of fermented material. Fermentation Chamber of the plant was constructed by the interconnected concrete rings. Each fermentation chamber was made from eight concrete rings. Each concrete ring was 0.26 m in height and 1.21 m in diameter. The total depth of each fermentation chamber was 2 m along with 1.21 m in diameter. The volume of each fermentation chamber is 9.2 m³.

The first concrete ring was placed at the concrete damp and plastered with the damp as shown in Figure 1. The second concrete ring was placed at the top of first concrete ring and plastered with cement. Similarly eight concrete rings were placed on one another to complete the fermentation chamber as shown in Figure 2. The concrete rings were plastered inside and outside with cement to avoid leakage. A bricks wall of 0.22 m width was constructed around the concrete rings at 0.15 m space for placing of insulating material into it to maintain temperature of fermentation chamber.

2.1.2 Feeding chamber
The Feeding chamber was made of cement and bricks having size of 0.91m long, 0.60 m wide and 0.30 m deep. The feeding Chamber was constructed 0.91 m above the ground to achieve gravity feeding of the materials.

2.1.3 Feeding inlet

The PVC pipe having 0.10 m diameter and 0.60 m in length was placed at the bottom of the fermentation chamber at an angle of 45 degree to feed the material from feeding chamber to fermentation chamber. The PVC pipe was fitted in such a way that its inlet was in the feeding chamber and its outlet was entered in the fermentation chamber one foot above the bottom of fermentation chamber.

2.1.4 Slurry outlet

The slurry outlet was made of PVC pipe having 0.10 m diameter and placed 0.46 m below the top of fermentation chamber to take the slurry out from the fermentation chamber. The slurry outlet end was above and its inlet end was below inside the fermentation chamber to keep it dipped always in the slurry to avoid gas leakage.

Figure 1: First concrete rings placed at the bottom on concrete damp for erection of fermentation chamber

3. Results and discussion

3.1 Slurry Temperature

3.1.1 Fresh material digester (FMD): In the FMD, the maximum values of slurry temperature for treatment BD, BD+CD and BD+SW were recorded 37°C, 35°C and 34°C, respectively. The minimum values of slurry temperature for treatment BD, BD+CD and BD+SW were found 32°C, 29°C and 27°C, respectively. The curve for the treatment BD showed continuous increase in slurry temperature from 32°C to 37°C due to increase in ambient temperature from 32°C to 37°C due to increase in ambient temperature from 37°C to 41°C as shown in the Figure 6. On the 10th day curve showed sudden drop in slurry temperature due to drop in ambient temperature which was due to rainfall on that day. The curve for treatment BD+CD, showed decreasing trend in slurry temperature due to decrease in ambient temperature as shown in the Figure 8 but after that curved showed regular increase in slurry temperature up to 35°C. On the 9th day the slurry temperature dropped due to drop in ambient temperature. The curve for the treatment BD+SW,
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showed increase in slurry temperature due to increase in ambient temperature up to 4th day as shown in the Figure 10 but on the 5th day there was sudden drop in slurry temperature due to drop in ambient temperature. The slurry temperature was again increased on 7th day due to increase in ambient temperature but after that curve showed regular decrease in slurry temperature from 32°C to 27°C. This was happened due to decrease in ambient temperature from 35°C to 31°C as it was due to rainfall.

3.1.2 Slurry feeding digester (SFD): The temperatures observed in slurry treatments were almost similar as it were observed in fresh material treatments. The slurry treatment of BD, BD+CD and BD+SW gave the maximum slurry temperature 37°C, 35°C and 35°C, respectively. The treatment BD curve showed increase in slurry temperature from 31°C to 34°C due to rise in ambient temperature from 37°C to 39°C as shown in the Figure 7. On the 5th day curve showed sudden drop in slurry temperature and it was due to lower ambient temperature but after that the curve showed continuous increase in slurry temperature up to 37°C. On 10th day the slurry temperature was again decreased due to drop in ambient temperature which was occurred due to rainfall on that day. The slurry treatment BD+CD, curve showed continuously increased in slurry temperature from 29°C to 35°C with the increase in ambient temperature from 32°C to 38°C. On 9th day curve showed decrease in slurry temperature with the decrease in ambient temperature which was due to rainfall on that day as shown in Figure 9. The slurry treatment BD+SW, curve showed continuous rise in slurry temperature from 29°C to 34°C with the rise in ambient temperature from 32°C to 40°C as shown in the Figure 11. After that slurry temperature decreased from 34°C to 27°C due to decrease in ambient temperature and it was due to rainfall on that day.

3.2 Gas Production

3.2.1 Fresh material digester (FMD): The maximum biogas production for treatment BD, BD+CD and BD+SW was recorded 0.46 m³/day, 0.51 m³/day and 0.50 m³/day respectively as shown in the Figure 4. The treatment BD+CD gave 23% more biogas production as compared to treatment BD. The treatment BD+SW gave 3.2% and 27% more biogas production as compared to treatment BD+CD and BD respectively. The biogas production for treatment BD gave sudden drop in biogas production on 3rd and increased gradually form 0.31 m³ to 0.47 m³. On the 10th day biogas production decreased due to decrease in slurry temperature and lower bacterial activities. The total biogas production in ten days for treatment BD recorded was 3.47 m³. The biogas production for the Treatment BD+CD, biogas production decreased initially and increased up to 0.51 m³ but on the 9th day curve showed sudden drop in slurry temperature due to drop in ambient temperature.

Table 1: pH values for fresh material digester (FMD)

<table>
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<tr>
<th>Treatments</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Mean</th>
</tr>
</thead>
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<tr>
<td>BD</td>
<td>7.06</td>
<td>7.09</td>
<td>7.11</td>
<td>7.14</td>
<td>7.15</td>
<td>7.18</td>
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<td>7.25</td>
<td>7.29</td>
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</tr>
<tr>
<td>BD+CD</td>
<td>7.20</td>
<td>7.23</td>
<td>7.26</td>
<td>7.27</td>
<td>7.29</td>
<td>7.30</td>
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<td>7.35</td>
<td>7.35</td>
<td>7.36</td>
<td>7.29</td>
</tr>
<tr>
<td>BD+SW</td>
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<td>7.24</td>
<td>7.26</td>
<td>7.29</td>
<td>7.30</td>
<td>7.28</td>
<td>7.32</td>
<td>7.32</td>
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</table>
The total yield of biogas in ten days for treatment of BD+SW recorded was 4.75 m$^3$. The increase in biogas production was due to increasing slurry temperature and more bacterial activities. The decrease in biogas production was due to decreasing slurry temperature and lowering bacterial activities. The treatment BD+SW gave 27% and 3.2% more biogas production as compared to treatments of BD and BD+CD, respectively.

### 3.2.2 Slurry feeding digester (SFD):

The maximum biogas production from slurry treatment of BD, BD+CD and BD+SW was recorded 0.31 m$^3$/day, 0.33 m$^3$/day and 0.34 m$^3$/day respectively as shown in the Figure 5. The slurry treatment BD+CD gave 43% more biogas production as compared to treatment BD. The slurry treatment of BD+SW gave 3% and 47% more biogas production as compared to slurry treatments of BD+CD and BD respectively. The biogas production from slurry treatment of BD was almost constant for the first six days because of same slurry temperature as shown in the Figure 5. On 7th day curve showed sudden increase in the biogas production. The total amount of biogas production in ten days from slurry treatment of BD recorded was 2.16 m$^3$. The slurry treatment of BD+CD treatment showed drop in biogas production on 2nd day as shown in the Figure 5 but after that biogas production was increased from 0.27 m$^3$/day to 0.33 m$^3$/day. The total yield of biogas in ten days from slurry treatment of BD+CD recorded was 3.09 m$^3$. The slurry treatment of BD+SW gave increasing and then decreasing trend in biogas production as shown in the Figure 5. The total biogas production from slurry treatment of BD+SW in days recorded was 3.18 m$^3$. The increase in biogas production was observed due to increased slurry temperature and more bacterial activities. The decrease in biogas production was observed due to decreased slurry temperature and reduced bacterial activities.

### 3.3 pH Value

#### 3.3.1 Fresh material digester (FMD):

The pH values of the three treatments remained between 7.06 and 7.36. The maximum values of pH for the treatment BD, BD+CD and BD+SW were recorded from 7.29, 7.36 and 7.34, respectively (Table 1). The minimum values of pH were recorded 7.06, 7.20 and 7.21 respectively. The low digestibility of the material resulted into low degradation of crude fibr and caused rise in pH value.

#### 3.3.2 Slurry feeding digester (SFD):

The pH values of the three slurry treatments remained between 7.06 to 7.37. The maximum pH values for the slurry

<table>
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<th>Treatments</th>
<th>Days</th>
<th>Mean</th>
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<tr>
<td>BD</td>
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<tr>
<td>BD+CD</td>
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<td>BD+SW</td>
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</table>
Figure 4: Biogas production in FMD for three treatments

Figure 5: Biogas production in SFD for three treatments

Figure 6: Effect of ambient temperature on slurry temperature for treatment BD in FMD

Figure 7: Effect of ambient temperature on slurry temperature for slurry treatment BD in SFD

Figure 8: Effect of ambient temperature on slurry temperature for treatment BD+CD in FMD

Figure 9: Effect of ambient temperature on slurry temperature for slurry treatment BD+CD in SFD
The treatment of BD, BD+CD and BD+SW, were recorded 7.28, 7.37 and 7.36, respectively (Table 2). The minimum pH values were recorded 7.06, 7.21 and 7.23 for the slurry treatment BD, BD+CD and BD+SW, respectively. The pH values were observed same as were in fresh material treatment digester.

### 3.3.3 Slurry analysis:

Slurry analysis was performed before and after the digestion for Total Organic Contents (TOC) Total Nitrogen (N), Total Phosphorus (P) and Total Potassium (K) to check its nutrients value for Bio fertilizer. The results showed significant increase in the values of nutrients after the digestion. The treatment BD gave 9.7%, 9.2%, 8.51% and 9.5% more values of TOC, Total N, Total P and Total K, respectively after the digestion. The treatment BD+CD gave 3.5%, 6.7%, 4% and 11% more values of TOC, Total N, Total P and Total K, respectively after the digestion. The treatment BD+SW gave 2.6%, 4.34%, 5.9% and 6.8% more values of TOC, Total N, Total P and Total K, respectively (Table 3).

### 4. CONCLUSION

The small biogas household plant was consisted of two digesters first Fresh Material Digester (FMD) and second Slurry Fed Digester (SFD) in series. The FMD was fed with fresh material and the SFD was fed automatically with slurry coming out of the FMD to extract gas left in the slurry. The small size biogas plant was constructed with concrete rings available in the market instead of bricks and cement. The total depth of each fermentation chamber was 6 feet and 8 inches along with 4 feet in diameter. The volume of each fermentation chamber is 9.2 m$^3$. The household plant fulfills the cooking requirement of 3-4 family members. The construction cost of this biogas plant is Rs 50000 and operational cost comes to Rs 46/h. The highest Biogas production was recorded 0.51 m$^3$/day, 0.50 m$^3$/day and 0.46 m$^3$/day from BD+CD, BD+SW and BD treatments, respectively in FMD. The biogas production recorded were 0.34 m$^3$/day, 0.33 m$^3$/day and 0.31 m$^3$/day from slurry treatments BD+SW, BD+CD and BD, respectively in SFD. The total biogas production in ten days from BD, BD+CD and BD+SW treatments recorded were 3.47 m$^3$, 4.6 m$^3$ and 4.75 m$^3$, respectively in FMD and 2.16 m$^3$, 3.09 m$^3$ and 3.18 m$^3$, respectively in SFD. It is concluded that the FMD gave 55% more biogas production as compared to SFD. The treatment BD+SW gave 27% and 3.2% more biogas production as compared to treatments of BD and BD+CD, respectively. The average slurry temperature in all treatments remained between 29°C to 37°C, approximately 5-6°C below the ambient temperature in FMD and SFD. The pH values were observed same in both FMD and SFD. The SFD gave gas production about 45% of the FMD gas production.
Table 3: Results of Slurry Analysis before and after Digestion

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<th>After Digestion</th>
<th>% Increase</th>
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<td>Total P( mgg⁻¹)</td>
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<td>Total K( mgg⁻¹)</td>
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<td>BD+CD</td>
<td>TOC ( mgg⁻¹)</td>
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<tr>
<td>BD+SW</td>
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5. References


