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DESIGN OF BIOGAS FERMENTATION CHAMBER AND TECHNIQUES TO ENRICH BIO-METHANATION

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This research work was conducted to design an algorithm for the biogas digester and demonstration of modern techniques to enrich the bio-methanation process. Initially, algorithms were generated and validated by design and operating digesters at selected sites. The designing and operational enhancement of biogas production were carried out using reverse blasting technique (RBT) at different sites *i.e.*, University of Agriculture Faisalabad (UAF) biogas plant, Proka farm, Chawla and Shakargarh biogas plants. Reverse blasting technique involves compression and injection of produced biogas to increase agitation within the digester leading to the deformation of scum. This action takes place at the top half of the digester resulting in the enhancement of microbial activity at the operating conditions. The analysis revealed that the biogas production rate was increased by 10% by controlling parameters such as reverse blasting pressure (2.5-5.5bar), temperature (30-40^{o}C), and feeding material density (1-2 kgm^{-3}). The obtained biogas was further enriched methane from 55 to 90% via chemical absorption method (CAM) using various solution concentrations of CaO and NaOH. The obtained enriched biogas was utilized for heating and power generation systems.
Keywords: Digester designing, biogas production, reverse blasting technique, enrichment, chemical absorption technique.

INTRODUCTION

Renewable energy has recently drawn significant attention from policymakers and researchers around the world as a result of its environmentally friendly nature. The world is now moving towards reliable and feasible hybrid renewable energy due to the depletion of fossil fuel and the negative effect on the environment as well as the potential techno-economic merits of hybrid combinations (Sawle *et al.*, 2018). Pakistan is a developing country and its increasing population and industrialization has resulted in a drastic increase in energy consumption. The energy mix of Pakistan during 2011-2012 accounted for natural gas as 49.5% followed by oil 30.8%, hydroelectricity 12.5%, coal 6.6%, nuclear electricity 1.9%, liquid petroleum gas 0.5%, and imported electricity 0.1% respectively (Ghafoor *et al.*, 2016). During 2016, the consolidated energy harnessed in the country was approximately equivalent to 85.75 million tons of oil equivalence (MTOE) (Ahmed *et al.*, 2016). Pakistan spends almost 14.5 billion US$ on import of fossil fuels annually to congregate its energy needs (Uddin *et al.*, 2016). In 2016, the scarcity of energy in Pakistan is approximately 5000 megawatt (MW) of electrical supply (Aized *et al.*, 2018). This problem will further aggravate in future because national energy demand is also increasing at an average annual rate of 5.67%. Moreover, the issues of climate change and environmental pollution are serious concerns that are attributed with the consumption of fossil fuels. Realizing the situation, developed countries have already started intensive research to explore sustainable and renewable energy resources (Donkin *et al.*, 2013).

There is immense potential for energy generation from waste produced in food processing industries, but the calculation of its amount cannot be ascertained due to its dependence upon the use of processing and production technology utilized (Forgacs *et al.*, 2011). According to a study on biogas plants, the average percentage of methane in the biogas produced was 55%, with a specific biogas production of 0.22 m^3kg^{-1} of feed material (Calise *et al.*, 2015). Around 81 million tons of crop residue, 72 million cows and buffaloes, and nearly 785 million birds produce residue and waste in Pakistan. Similarly, daily availability of dung is 360 million kg from animals, while, 30 million kg from birds with the rate of 50% collectability. This organic waste is producing approximately 41 million kilowatt hour (kWh) units of electricity daily and about 13,530 gigawatt hour annually.

Decentralized applications are used to address the rural community because in contrast with other renewable energy resources, biogas is the cheapest source of energy. It consists of 50-65% methane through anaerobic digestion of animal dung and can be stored for cooking, heating applications as well as for power generation. As a source of energy, anaerobic digestion technology also produces slurry as organic waste (Al-Addous *et al.*, 2017)**.** Usually, total solids of cow manure are 7-9% (Angelidaki and Ellegaard, 2003), while of dairy buffaloes total solids range is 8.1-8.3% (di-Perta *et al.*, 2019). The rural community has great potential to utilize its resources but unfortunately, lack of technologies, research and development in the past have restricted the use of biogas plants. Although the country has abundant animals that are producing ample of dung which is thrown into open space thus causing environmental pollution and health issues in the community. So, biogas plants are the only solution for farmers as well as for the people of rural community. During anaerobic digestion in the fermentation chamber, the mixing process has a significant effect on biogas production (Samani *et al.*, 2017) due to the homogenization of organic waste which not only breaks scum formation but also prevents dead-zone occurrence inside the fermentation chamber to maintain the bacterial activity (Nsair *et al.*, 2018). The purpose of mixing is to distribute nutrients uniformity within the digester (Zabaleta and Rodic, 2015) to create a suspension of liquid and solid parts to avoid sedimentation of particles (Naegele *et al.*, 2014) as well as to ensure uniform heat distribution (Hosseini and Wahid, 2014).

This present study enables not only the installation of a floating drum biogas plant by using the mixing mechanism to enhance their biological process during anaerobic digestion but also increases plant efficiency. The existing design was restricted to a domestic level biogas plant to facilitate the poor farming community in rural areas. The objective of this study is to enhance biogas production for comprehensive and effective adaptation, particularly in remote and power-deprived areas. This research was carried out by performing experiments using the reverse blasting technique. The data were collected from UAF and Shakargarh biogas plants (having mechanical agitation systems) and these results were compared with Chawla, Proka sites where reverse blasting technique was applied. Further, the obtained biogas was enriched by applying a chemical absorption method and utilized to generate power.

MATERIALS AND METHODS

This article presents the complete algorithm of designing a floating drum biogas plant in terms of calculation for volume, diameter, height, and depth of fermentation chamber as well as the capacity of thermal power and gas engines (genset) used for power generation. This research was conducted simultaneously at four sites of biogas plants (UAF, Proka, Chawla, and Shakargarh sites). These plants were designed and constructed based on a specific algorithm and have been running successfully. Initially, an algorithm was designed to investigate the quantity of biodegradable material required for energy and power generation. The algorithm was validated by the performance evaluation of these plants in terms of biogas production.

Digester design on specific energy demand: The algorithm was used to determine the size of fermentation chamber and for biodegradable material to be used for specific energy/ power demand on site. A case study of one of the floating drum biogas plant at Proka site is also presented for practical justification of this algorithm. By keeping engine power and time of operation specified for a particular size, the energy required was determined using Eq. (3.1) (Knight, 2008).

$$E_d = P_s t \qquad (3.1)$$

Where 'E_d' is total energy required in kilowatt hour (kWh) to run the specified size of an engine 'P_s' in power in kilowatt (kW) and 't' is time of operation in hours.

Normally 6-12 hours of operating time were recommended for daily operation of an IC engine. However, this duration can be increased or decreased accordingly to energy requirement at farm. For a previous case study of Proka Biogas plants, a 20 kW capacity engine size was selected for six hour operation per day to run a gas engine for farm use (tube well, fodder machine, small farm electrical appliances, etc.). The total energy required in a day was estimated to be 114 kWh. Therefore, volume of biogas required 'V_g' in cubic meter per day was calculated using Eq. (3.2).

$$V_g = E_d C_{sp} \qquad (3.2)$$

Where 'E_d' is total energy ($kWhday^{-1}$) to run the required load and 'C_{sp}' is specific gas consumption of the gas engine in $m^3kW^{-1}h^{-1}$ of the gas engine working on Otto cycle and its value was taken as 0.402 $m^3kW^{-1}h^{-1}$ for the gas engine. Under the operational parameter of the plant, the volume of gas required for the engine operation in a day was calculated to be 46.36 m^3day^{-1} using Eq. 3.2.

Mass of required biodegradable material 'M_d' ($kgday^{-1}$) inside the fermentation chamber was calculated using Eq. (3.3).

$$M_d = \frac{V_g}{V_u} \qquad (3.3)$$

Where 'V_u' is actual gas produced per unit mass of biodegradable material in m^3kg^{-1}. The actual gas produced per kg of animal dung under practical condition is 0.035 m^3kg^{-1} (Approx. 70% of 0.05 m^3kg^{-1}). The animal dung required per day was calculated to be 2600 kg and this animal dung was obtained from about 260 cows/ buffaloes (@ 10-11 kg/ animal/ day) available at Proka farms.

The feeding material was prepared using a 1:1 dung to water ratio, so the total mass of daily charge 'M_c' in the fermentation chamber was found to be 5188 kg.

Therefore, volume of daily charge 'V_c' in cubic meter was calculated using Eq. (3.4)

$$V_c = \frac{M_c}{d_f} \qquad (3.4)$$

Where 'V_c' is volume of daily charge in m^3, 'M_c' is mass of daily charge in kg and d_f is the density of feeding material (biodegradable material + water) in kgm^{-3}. For animal dung (cow and buffalo) and water ratio at 1:1 ratio, the density (d_f) is found to be 1090 kgm^{-3}. So, volume of daily charge 'V_c' was calculated to be 4.75 m^3 using Eq. (3.4).

The total volume of the digester (V_d) was calculated using Eq. (3.5).

$$V_d = V_c t_r \tag{3.5}$$

Similarly, hydraulic retention time (HRT) 't_r' depends on temperature at the site to enhance microbial activity in the mesophilic range. Usually retention time under the sub-tropical conditions of selected sites is taken as 30 days. Thus, the volume of the digester of the Proka Farms is calculated to be 130.6 m^3. This is, however, theoretical value; under practical condition, a 10% provision for sedimentation has been taken into account to increase the plant capacity. Thus, the total volume of the fermentation chamber *(V_t)* is given below in Eq. (3.6).

$$V_t = V_d(1 + x) \tag{3.6}$$

Where 'x' is the sedimentation provision. Using the above equation, the total volume of the fermentation chamber was calculated to be 142.60 m^3. The results have shown that the total volume of the fermentation chamber required for Genset operation was 130 m^3 biogas plant.

The floating drum biogas plants were cylindrical, so the diameter (D) of the fermentation chamber was calculated using Eq. (3.7) (Jaya and Maurya, 2017)

$$D = \sqrt[3]{\frac{4V_t}{\pi r_{h/d}}} \tag{3.7}$$

Where '$r_{h/d}$' is height to diameter ratio of the fermentation chamber which depends on the location of the site and is selected based on water table depth, soil type, and available sunshine area etc. However, the best value of $r_{h/d}$ for the floating drum biogas plant is taken from 0.75 - 1.50.

The height of the fermentation (H) chamber is calculated by the following equation (Eq. 3.8)

$$H = r_{h/d} D \tag{3.8}$$

Where '$r_{h/d}$' is the height to diameter ratio of the fermentation chamber for the particular location and its value varies from 0.75 – 1.50 depending upon the specific location of the biogas plant. Based on these calculations, the floating drum biogas plant at Proka farm was calculated. The same algorithm has been used to design biogas plants digesters at UAF, Chawla and Shakargarh biogas plants.

Development of various components of biogas plants**:** The optimal design of a biogas plant is necessary to maximize biogas production. Considering the availability of significant resources in the form of animal waste and biomass in the country, this study was carried out for the design, development, and performance evaluation of indigenized floating drum biogas plants for decentralized rural applications. The following are the main components of designed biogas plants at various sites.

Fermentation chamber/digester**:** A digester (fermentation chamber) is a pit of different volume to hold the feeding material for a specific period. These are floating drum biogas plants. There were different digesters having volumes of 25, 40, 110, and 130 m^3 respectively. These digesters were constructed fully with sand, cement, gravels, and bricks. The walls of the digesters were plastered with a mixture of sand and cement in a ratio of 1:4. The base of the fermentation chambers was constructed thick and damp proof to avoid any possible leakage. To maintain the temperature inside the digester at the optimum range (30-40°C), a stainless-steel heat exchanger was also coupled with the geyser for continuous circulation of hot water supply to maintain optimum temperature during winter season. Stirrer was used to mix the material manually/mechanically in the fermentation chamber. Another technique for maintaining the anaerobic digestion, commonly called as reverse blasting technique in which a circular shape of PVC pipe (22 mm) circulated at the bottom of the digester by designing on pneumatic pressure for proper mixing of the dung and water for homogeneous mixture to maintain optimum temperature range (30-40°C). In Pakistan, there were common problems during the installation of biogas plants such as scum formation, drum tilting, clogging of inlet and outlet pipes, and gas leakage problems. Nowadays, modifications in the digester design are made based on pneumatic pressure circulation to provide homogenized mixing and maintain digester inside temperature in the mesophilic range (30-40°C) to improve their methanogenic process. The diagram of a fermentation chamber at Proka Farms is shown in Figure 1.

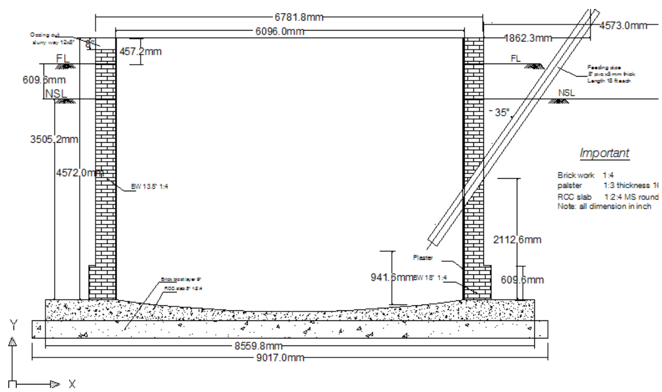


Figure 1. Sectional view of the fermentation chamber installed at Proka Farms, Faisalabad.

Feeding tank**:** The feeding chamber was used to add animal dung and water and a mixer is installed at top of the feeding chamber to mix dung and water for a homogeneous mixture to facilitate anaerobic fermentation in the digester. The height and diameter of the cylindrical feeding tank are 16775 mm and 1524 x1828.8 mm respectively to make a total volume of 1.16 m^3 and the same size was selected for all biogas plants as its function is only to feed the material independent of the size of fermentation chamber. The feeding chamber was constructed on a solid circular base of brickwork and concrete (concrete, cement, and clay ration as 1:2:4, respectively).

To maintain optimum Carbon to Nitrogen (C/N) ratio, animal dung and water were mixed at 1:1 ratio by weight. A submersible pump in a closed circuit was also employed for the mixing of animal dung and water for homogenization. The pump takes the material from the feeding chamber and mixes thoroughly before the material is shifted into the digester. The submersible pump type used is the hermetically sealed pump operated by pushing rather than pulling fluid during its pumping process. The level of the feeding tank was a little bit higher than the level of sludge outlet. A cylindrical shaped PVC pipe (150 mm) is used to connect the feeding chamber with the digester. Biodegradable material from the feeding chamber (Figure 2) after mixing and homogenization, is fed into the digester/fermentation process for biogas production through an anaerobic fermentation process.

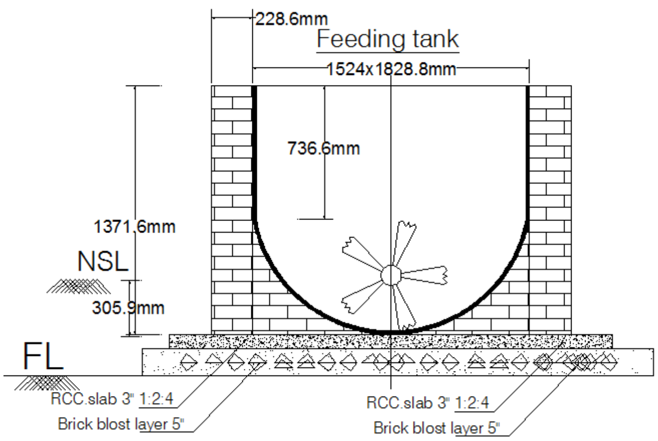


Figure 2. Sectional view of feeding tank installed at Proka Farms, Faisalabad.

Gasholder: Each digester was provided with a floating drum of fiberglass with a canopy outer diameter as 5892.8 mm top and bottom ring of pipe diameter as 42.16 mm, the curve type pipe round/square 21.33 mm while straight vertical height as 1371.6 mm along with curved surface having 762 mm (Figure 3). About 60-75% of daily biogas production was stored in the gas holder and it worked at constant pressure due to its floating nature. The biogas from the gas holder was extracted to the gasholder by using compressors. A cylindrical-shaped drum with a conical dome was selected as a gas holder for collecting the gas.

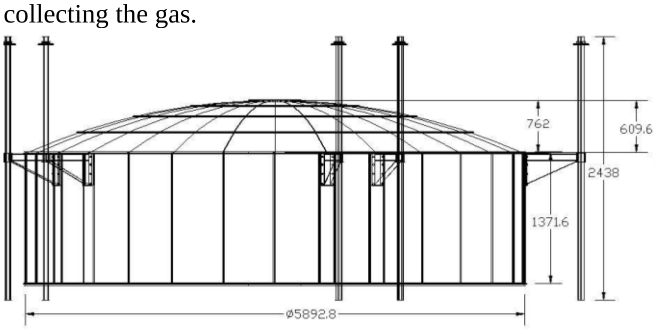


Figure 3. Sectional view of gasholder installed at Proka Farms, Faisalabad.

***Mechanical stirring*:** In the mechanical stirring, a stain-less-steel horizontal shaft stirring mechanism having three arms was provided to mix feeding material in the digester. It was operated 2 or 3 times per day manually and mechanically. The mixing facilitated the microbes to maintain their population. It prevented the formation of dead pockets in the digester that increased plant efficiency. This system is installed at main campus of UAF and at Shakargarh biogas plants.

***Reverse blasting technique*:** The indigenized reverse blasting technique is also incorporated at Proka Biogas Plant and Chawla biogas plant for comparison. In hydraulic stirring, circular shape of PVC pipes circulated at the bottom of the digester by designing on pneumatic pressure for proper mixing of the dung and water for homogeneous mixture by maintaining their biological process. These pipes laid at the bottom of the digester in a circular manner having a diameter of 22 mm. An indigenous reverse blasting technique is shown in Figure 4.

Figure 4. Installation of reverse blasting technique inside the digester.

A pipe of 16 mm diameter was connected to a storage tank, a pressure regulator valve attached with a compressor, which diverts the required biogas towards the bottom of the digester. Biogas was recirculated in the digester through a pipe, laid on the bottom of the digester in a circular shape, and having fixed nozzles on its surface to exhaust the pressurized biogas from bottoms towards the top. This was operated 2 or 3 times daily by passing the pressurized biogas from the bottom of the digester. It prevents scum formation of dead pockets in the digester to increases the plant efficiency. By this process, anaerobic fermentation occurs rapidly. Therefore, the mechanical agitator was demolished, and the biogas plant economized. Above mentioned modifications in the biogas plants have increased the biogas production by up to 10%.

***Gas heat exchanger for temperature maintenance*:** To maintain optimum temperature range during winter season (when the ambient temperature drops to even 0°C or even less than this during some seasons), a state of the art heat exchange system has been incorporated to maintain temperature in the range of 35-40°C inside the fermentation chamber. For this purpose, a stainless steel (non-corrosive) coil having a diameter of 50 mm is installed along the inner wall of the fermentation chamber and stirring of the feeding martial automatically maintains uniform temperature of the whole matrix. The heat is provided by biogas using conventional geysers available in the markets for household applications. A circulation centrifugal type pump is used to ensure the circulation of hot water and a thermostat valve automatically opens and closes the pump when the circulation of hot water is required to maintain the optimum temperature range (30-40°C) inside the fermentation chamber. The maximum achievable methane concentration was found to be 54% at the digester temperature of 40°C at variable operating pressure ranges from 2.5-5.50 bar while the density of feeding material was maintained from 1-2 kgm^{-3}. The purpose of this study was to conduct experiments for maintaining the temperature in the mesophilic range.

***Gas handling, storage, and power generation*:** Two compressors have been used for storing biogas at elevated pressure into storage vessels at a maximum of 10 bar operating pressure and biogas is used to operate the Gensets employing a pressure reducing valve. Compressors were installed after the scrubbing unit (double piston V-shaped coupled with 1 kW electric motor) to compress the purified biogas into storage vessels up to 1000 kPa pressure. The storage chambers are cylindrical in shape and having 5-10 mm of wall thickness and gas was stored at 500 kPa pressure keeping in view the safety factor, shut off switches have been used to switch on and off compressors automatically to maintain permissible pressure inside the compressor storage vessels when there is significant biogas available in gasholders. Limit switches have also been used near the fermentation chambers to de-circuit the compressor and prevent the gas holder from damage when all the gas has been shifted to gas storage vessels from the gasholder. Genset was employed for introducing electrification at farms. There are more than 300 animals (buffalos & cows) available at Chawla farm, Satiana road and UAF Proka farm Faisalabad. In this way, the dung was easily available for feeding the digester to produce biogas. After producing biogas, it is coupled with a 20 kW generator installed at Chawla farm Satiana road Faisalabad. For the optimum design of the floating drum biogas plant, the above design equations were used to calculate the daily mass, diameter, height, volume, power, and energy. The size of an inlet tank was made fixed depending upon the quantity of dung to be fed into the plant per day. Feeding rates were also calculated according to the size and requirement of the biogas plant. A schematic of floating drum biogas plants installed at Chawla farm is given in Figure 5.

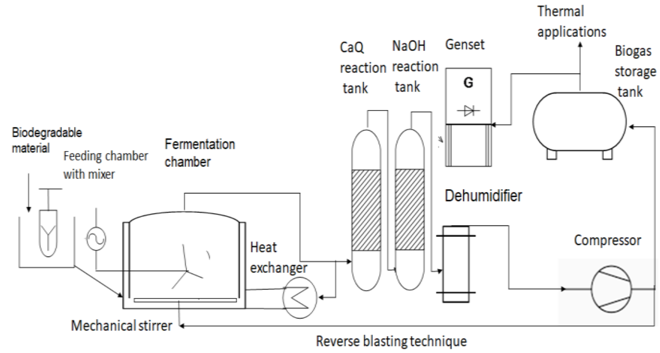


Figure 5. Schematic of a modern floating drum biogas plant with all biogas enrichment units used during research work.

***Filtering units*:** For the removal of unwanted gases from biogas, dehumidifier (for removing water vapors) and H_2S scrubber (for removing H_2S) are used.

***Dehumidifier*:** Biogas contains moisture contents (3-10%) and will cause corrosion if directly used. To avoid this problem, a dehumidifier containing silica gel was designed and developed to absorb moisture contents present in the biogas.

***H_2S scrubber*:** Hydrogen sulfide content ranges from 50-5000 ppm in the biogas. Removal of these contaminants is necessary because these contaminants damage the engine parts during combustion. Construction of the H_2S scrubber is same as that of the dehumidifier but iron wools are used in it. Iron wools react with hydrogen sulfide to form iron sulfide. In this process, hydrogen gas is liberated. The chemical reaction is given below in Eq (3.9).

$$Fe + H_2S \rightarrow \mathrm{FeS} + H_2 \qquad (3.9)$$

In small scale biogas plants, a set of dehumidifiers and H_2S scrubber filled with iron wools fulfill the requirement of removing water and H_2S to run a gas engine without the use of chemical absorption techniques to purify biogas.

***Chemical absorption method*:** The chemical absorption method for up-grading biogas by using different chemicals provided below. Raw biogas was purified by different chemical processes and reaction tanks were designed with the following dimensions as given in Table 1.

Table 1. Height and diameter of biogas up-gradation unit.

Diameter of column (A)	0.462 m
Height of column (A)	1.23 m
Diameter of column (B)	0.462 m
Height of column (B)	1.23 m

The chemical absorption technique is a chemical treatment process for upgrading biogas by using different chemicals placed in a reaction tank. The up-gradation of biogas was achieved by the following two steps procedure. In the first section, a solution of $CaO+H_2O$ is prepared with different quantities of a solution to check the solubility of biogas with variable flow rates and pressure of biogas. Secondly, a solution of $NaOH + H_2O$ is prepared with different quantities of solution to confirm the solubility of biogas with a variable flow rates and pressure of biogas. A temperature sensor also attached to verify the temperature and a pressure relief valve was also mounted at the top portion to release the excessive pressure during the exothermic reaction. The outlet of the water was also fitted at the lower side of this section.

Figure 6. UAF Biogas plants installed near dairy farms

Data on biogas production were collected from Chawla Farm Satiana Road Faisalabad. The variation in pressure and flow rate of biogas was recorded and their effect was observed. Biogas samples were analyzed using BIOGAS 5000. Central Composition, Response Surface of "The Design of Expert" Software 7.0® was used to analyze biogas production rates statistically.

RESULTS AND DISCUSSIONS

In this study, the biogas plant has been designed and developed using the algorithm and formulae. Biogas plant is an anaerobic process where microbial activity produces biogas due to hydrolysis process, acidogenic, acetogenesis and methanogenesis processes which are prolonged for several days. Keeping in view location of the site of Chawla Dairy Farm, the retention time was determined under laboratory conditions using the biodegradable material i.e.(dung) from farm and biogas production was noted on daily basis using a biogas analyzer 'BIOGAS-5000'.The results proved that the best hydraulic retention time under the condition of Faisalabad was found to be 30-45 days; however, under practical conditions when the temperature is high, the retention time is taken as 30 days. This plant was designed based on the energy required at the farm therefore energy was calculated as 114 kWh by using Eq 3.1 while volume of gas required for 24 hours was calculated to be 45.28 m^3 using Eq 3.2. To calculate the mass of daily charge, Eq. 3.3 was used and calculated to be 2600 kgd^{-1}. The volume of daily charge was calculated to be 4.75 m^3 using Eq. 3.4 keeping density of feeding material as 1090 kgm^{-3}. The theoretical volume of the digester was calculated to be 130.6 m^3 using Eq.3.5. So, considering a 10% provision for sedimentation provision, the total volume of the digester was calculated to be 142.5 m^3 using Eq. 3.6.

Since the floating drum biogas plant involves a cylindrical floating drum, so the diameter of the digester is required to be calculated. Thus, diameter of the digester was calculated to be 6096 mm using Eq. 3.7. The height to diameter ratio was used to adjust the diameter and height of biogas plants based on the availability of space and groundwater depth etc. Normally, the diameter to height ratio should be maintained between 0.75 - 1.50. After calculating the diameter of the biogas digester, the height of the biogas plant was calculated to be 4572 mm using Eq. 3.8.

Once the volume of digester was calculated, then the amount of theoretical biogas produced from biogas plant was calculated. The specific gas production per kg of animal dung was recorded to be 0.05 m^3kg^{-1} using BIOGAS-5000. Thus, the amount of biogas produced from 130 m^3 biogas plant using 2600 kg biodegradable/dung material was calculated to be 4.76 m^3day^{-1} using Eq. 3.5. This is a theoretical value of the biogas produced but it was rather difficult to maintain the ideal conditions due to temperature variation and other environmental factors. The specific gas consumptions for an engine working on-Otto cycle and Diesel cycle are 0.60 $m^3kW^{-1}h^{-1}$ and 0.45 $m^3kW^{-1}h^{-1}$, respectively at 70% efficiency of biogas plant. Out of 2600 kg animal dung, the total biogas produced was 90.86 m^3day^{-1} and continuous power 20 kW for six hours daily (1.19 m^3day^{-1}) can be generated using a gas engine working on Otto cycle. These results are similar with the findings of Agrahari and Tiwari (2011) as they obtained 1.512 m^3day^{-1} biogas per day. Two biogas storage tanks, each having 3.5 m^3 capacity has also been installed to store the biogas to run even a big capacity engine for running farm utensils and fodder machines, etc. when needed. Various parameters of proposed biogas plants have been detailed in Table 2.

After the designing of floating drum biogas plant having capacity of 130 m^3, the composition of biogas was analyzed using biogas analyzer (BIOGAS 5000; Error<1%) and the composition of CH_4, CO_2, NH_3, O_2, CO, H_2 and H_2S of biogas before scrubbing unit is given in Table 3.

From the results it can be concluded that the biogas plant can generate more than 50% CH_4 without using any scrubbing system or chemical treatment.

***Parametric study on biogas production rate*:** In this section, the combined effect of temperature, pressure, and feeding material ratio on the production of biogas has been examined and discussed in detail.

***Combined effect of feed material ratio and temperature on biogas production rate*:** Biogas production is normally

Table 2. Various parameters of proposed biogas plants.

Parameters	Chawla	UAF	Proka farms	Shakar Garh
Animals available at farm per day	300	300	260	200
Animal dung available (kg/d)	3000	3000	2600	2000
Feeding rate (kg/d)	2000	1005 kg (655 and 400)		
Dung water ratio	1:1	1:1	1:1	1:1
Density of material (kg/m$^{3)}$	1090	1090	1090	1090
Gas produced per day (m^3/d)		50		
Digester volume (m^3)	130	40+25	130+130	110
Digester Diameter (m)	4.78	3.9+3.30	6.09	4.53
Digester Height (m)	7.17	4.06+3.85	4.57	6.80
Storage tank capacity(m^3)	7 (two tanks with 3.5 m^3 each)	3 m^3 (two tanks with 1.5 each)	12(four tanks each 3m^3)	12 (four tanks each 3m^3)
Genset capacity	30	20	60	50
Per day usage	6	6	6	6
Energy per day	180	180	360	300

Table 3. Composition CH_4, CO_2, O_2, NH_3, CO, H_2 and H_2S of Biogas Plant installed at Dairy Farm.

CH_4 %	CO_2 %	O_2 %	Peak CH_4 %	Peak CO_2 %	Min O_2 %	NH_3 Ppm	CO ppm	H_2 lmh	H_2S Ppm
48	45.5	0.2	54.	45.5	0.2	>>>>	3	Low	5000

affected by feeding material ratio (water to dung ratio) and the temperature (°C). Raw biogas production rate (m^{3}h^{-1}) was increased by employing pneumatic pressure design commonly called a reverse blasting technique (RBT) during the anaerobic digestion process. As temperature reduces from 40 to 30°C, biogas production reduces from 33 to 28 m^{3}h^{-1}. As the feeding material ratio was increased, the biogas production rate (m^{3}h^{-1}) decreased, and vice versa. Figure 7 depicts that temperature has shown the highest effect on gas production rate followed by pressure and feeding ratio. The effect of feed material ratio was non-significant.

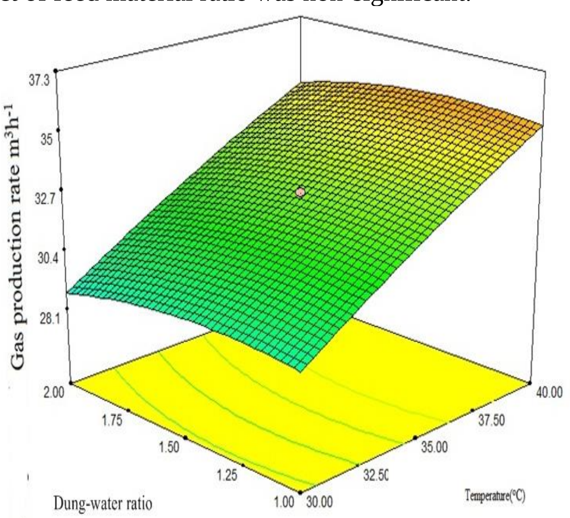


Figure 7. Effect of feed material ratio and digester temperature on biogas production

***Combined Effect of pressure and temperature on biogas production rate*:** Figure 8 shows that as the temperature increased inside the digester from 30 to 40°C and pressure increased from 2.5 to 5.5 bar of biogas which was entered from the bottom of the digester to maintain the anaerobic digestion process. Therefore, in this process the biogas production rate was observed to be increased significantly from 31 to 37 m^{3}h^{-1}. Statistically, the analysis proved that an increase in pressure (bar) and temperature (°C) for an optimum range gives a significant increase in biogas production rate (m^{3}h^{-1}).

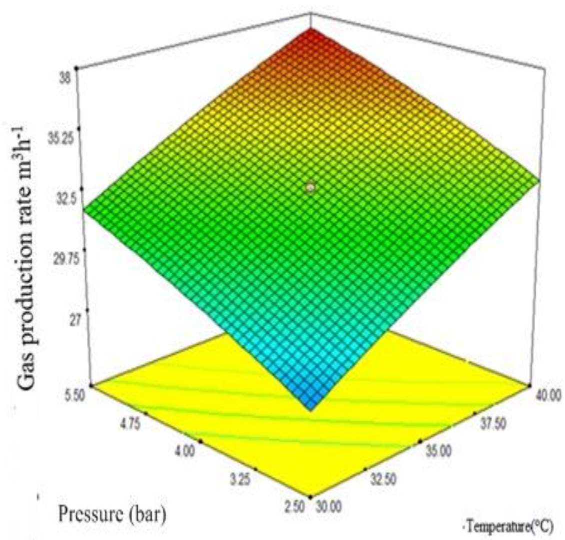


Figure 8. Effect of pressure and temperature on biogas production

Combine effect of pressure and feeding material density on biogas production rate: In this process of anaerobic digestion, effect of pressure and feeding material ratio significantly affected the biogas production rate (m^3h^{-1}) because when pressure of biogas increased from 2.5 to 5.5 bar the bacterial activity increased and breaking down scum formation in the fermentation chamber. Moreover, biogas production rate was increased from 31 to 35 m^3h^{-1} by increasing dung water ratio from 1-2 (water to dung ratio) for balancing the carbon to nitrogen ratio (C:N) as shown in Figure 9. Statistical analysis of gas production rate in terms of ANOVA was also applied and the results are shown in Table 4. Results showed that feed material ratio and pressure of biogas up to optimum level has a significant effect on biogas production. In all cases, the quantity of gas used for RBT was not taken into consideration but only the effect of pressure was analyzed.

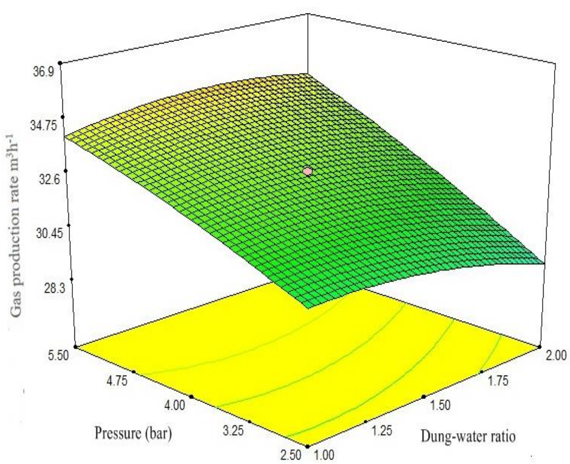


Figure 9. Effect of pressure and feed material ratio on biogas production

Table 4. Gas production rate (ANOVA).

Source	Sum of square	Df	M.S	F-value	P-value
Model	188.68	9	20.96	44.27	<0.0001
A-Temperature	114.09	1	114.09	240.91	<0.0001
B-Feeding	1.81	1	1.81	3.83	0.0788
C-Pressure	66.32	1	66.32	140.04	0.0001
AB	0.00	1	0.08	0.00	1.0000
AC	0.08	1	1.81	6.17	0.6897
BC	1.81	1	0.65	3.81	0.0794
A^2	0.65	1	3.79	1.37	0.2684
B^2	3.79	1	0.76	8.01	0.0179
C^2	0.76	10	0.47	1.61	0.2330
Lack of it	4.74	5	0.95		
Error	0.00	5			
Total	193.41	19			

Biogas enrichment through chemical absorption technique

***Effect of CaO and H_2O treatments on CH_4 concentration*:** Raw biogas contains 52.6% ± 0.7% methane. Methane concentration slightly increased when it reaches the storage tank (but it was not significantly different from that of raw biogas) as some of the water contents along with CO_2 were removed through a drain valve from time to time to prevent storage tanks from corrosion due to the presence of moisture contents (H_2O) and CO_2 inside it.

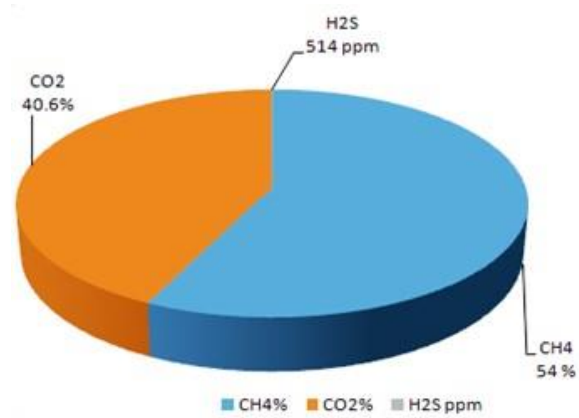
In chemical absorption technique using CaO and H_2O treatments on CH_4 concentration, the raw biogas entered from the bottom of the scrubbing system in which calcium oxide reacts with carbon dioxide to form insoluble calcium carbonate by absorbing CO_2 thus enriching bio-methanation. Calcium oxide also reacts with water to give rise to calcium hydroxide and this produced calcium hydroxide and it again reacts with CO_2 molecules to form insoluble $CaCO_3$ which further enriches biogas as detailed below in the following equations.

$$CaO + CO_2 \rightarrow CaCO_3 \quad (3.10)$$

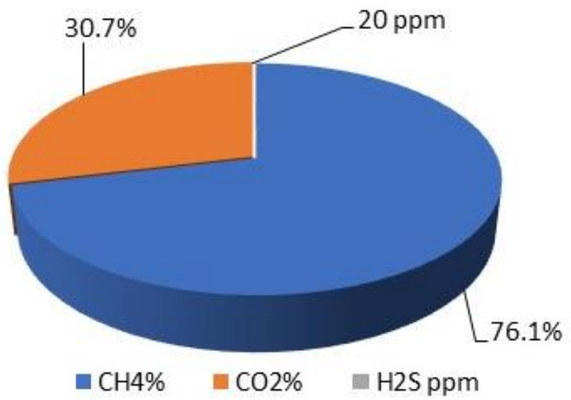
$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (3.11)$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (3.12)$$

It is evident from Figure 10(a) that the methane concentration (CH_4%) increased from 54.1 to 68% at a water column height of 15 cm and using 1 kg of CaO which clearly shows that the chemical absorption method has a significant effect on methane concentration.



(a) 1 kg CaO in 15 cm column height



(b) 4 kg CaO in 45 cm column height

Figure 10. Effect of NaOH and H_2O solution treatments on CH_4 (%) concentration

It is also evident in Figure 10(b) that when the column height was increased from 15 to 45 cm and the quantity of chemical was increased to 4 kg, methane concentration was increased to 76.1%. The findings of this study showed that there was a significant effect of column height as well as the quantity of CaO used in the reaction tank. It was also observed that there was no significant rise in CH_4 concentration on either increasing quantity of CaO or increasing column height of CaO. This research has revealed that significant effect of water column depth increased the contact area and retention time by adding more water up to a certain limit. Similarly, an increase in the quantity of CaO increased more quantity of biogas to take part in a chemical reaction, thus enhancing the quantity of CH_4 by absorbing more CO_2 in insoluble products in the reaction chamber.

***Effect of NaOH and H_2O mixture treatments on CH_4 concentration*:** In this method, carbon dioxide reacts with water to give rise to carbonic acid and this carbonic acid again reacts with sodium hydroxide in the second reaction tank to form sodium bi-carbonate and water and finally, sodium hydroxide reacts with carbon dioxide to form sodium carbonate and water as shown in the following equations.

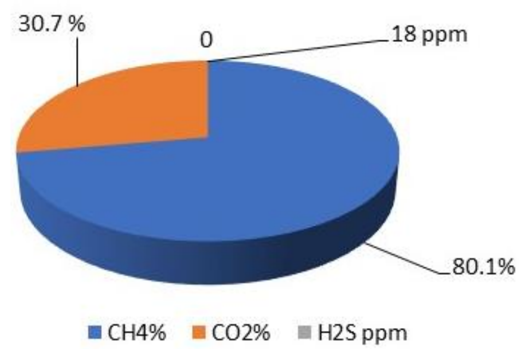
$$CO_2 + H_2O \rightarrow H_2CO_3 \quad (3.13)$$

$$H_2CO_3 + NaOH \rightarrow NaHCO_3 + H_2O \quad (3.14)$$

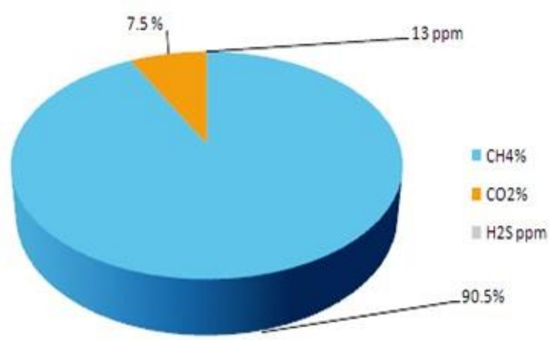
$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O \quad (3.15)$$

It is also clear from Figure 11(a) that methane concentration (CH_4%) increased from 76.1 to 80.1% at a water column height of 15 cm and using 1 kg of NaOH which clearly showed that the NaOH can be used to enrich biogas to high levels of bio-methanation. This is due to the reason that it is easy to break a single ionic bond compared to a double valiancy of CaO. Chemical absorption method showed a significant effect on methane concentration. It is also evident from Figure 11(b) that when the column height was increased from 15 to 45 cm and the quantity of chemical was increased to 4 kg, the methane concentration was increased to 90.5%. The research has shown that there is a significant effect of column height as well as the quantity of NaOH used in the reaction tank. This article has revealed that significant effect of water column height increased the retention time by adding more water up to a certain limit. Similarly, an increase in the quantity of NaOH increased more quantity of biogas to take part in chemical reaction to decompose CO_2% and H_2S ppm present in the biogas and to enrich CH_4%.

Applying chemical absorption technique resulted in enrichment of biogas the percentage composition of methane (CH_4%) was as high as up to 90% which is equivalent to natural gas (Sui Northern Gas Pipe Line Limited, Sngpl) having 90% methane content (CH_4%). Biogas consisting of 90% methane has proven beneficial for high engine performance but also the calorific value of biogas increased so that their heating and thermal applications were increased. A graphical presentation of combined chemical treatments (CaO+H_2O treatments and NaOH + H_2O) is shown in Figure 12. Only initial and final levels the number of chemicals (CaO+H_2O treatments and NaOH + H_2O) and height of the column have been shown. Figure 12 also depicted that there was a gradual increase in reduction of carbon dioxide CO_2% resulting in an increase in methane CH_4% concentration in biogas. CaO treatment method and the percentage remained constant even by increasing the quantity and CaO and increasing the height of the column of CaO. Thereafter, this gas passed through another reaction tank containing NaOH and H_2O which further absorbed CO_2 to enhance the composition of methane CH_4% more than 90%.



(a) kg CaO in 15 cm column height



(b) 4 kg CaO in 45 cm column height

Figure 11. Effect of NaOH and H_2O solution treatments on CH_4 (%) concentration.

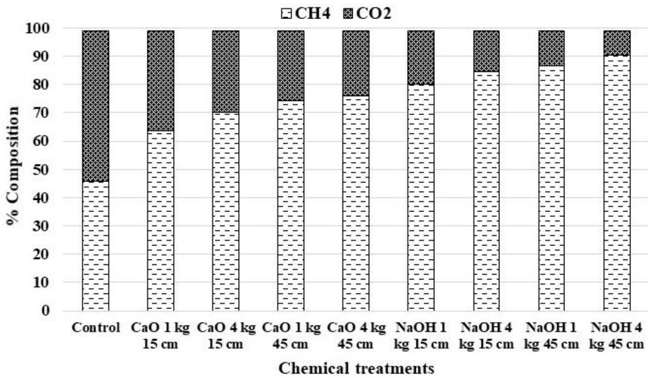


Figure 12. Effect of CaO+H_2O treatments and NaOH + H_2O on CH_4 and CO_2 concentration

***Effect of CaO+H_2O treatments on H_2S concentration*:** Several experiments were conducted to investigate the effect of "CaO+H_2O" on H_2S concentration in ppm. The solution of CaO and H_2O is first converted to $Ca(OH)_2$ and when biogas is passed through this solution in the reaction tank, the product of CaS and H_2O as well as calcium hydrogen sulfide are formed converting soluble H_2S into insoluble substances as detailed below in the given equations.

$$Ca(OH)_2 + H_2S \rightarrow CaS + 2H_2O \quad (3.16)$$

$$Ca(OH)_2 + 2H_2S \rightarrow Ca(HS)_2 + 2H_2O \quad (3.17)$$

Hydrogen sulfide gas reacts with water to form sulfuric acid and this sulfuric acid reacts with sodium hydroxide to form sodium sulfate, and water are shown in the given equations.

$$H_2S + H_2O \rightarrow H_2SO_4 \quad (3.18)$$

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O \quad (3.19)$$

Similarly, in the sodium hydroxide reaction tank, sodium hydroxide reacts with hydrogen sulfide forms sodium sulfide, and water is achieved. This is an exothermic reaction in which heat is liberated as shown in the following equation.

$$2NaOH + H_2S \rightarrow Na_2S + 2H_2O \quad (3.20)$$

Raw biogas contains 500-5000 ppm hydrogen sulfide. In this research, CaO and H_2O solution was used to indicate the absorption capacity of H_2S from the gas stream and found that it is a useful technique to remove H_2S from biogas. According to Shah *et al.* (2016) for the removal of hazardous gases like H_2S and moisture contents calcium oxide (CaO) and sodium hydroxide (NaOH) contributed 94.69% methane ($CH_{4\%}$) also by using dry lime and potassium hydroxide gives 95.1% methane (CH_4%) and H_2S reduces up to 87 ppm by using a combination of iron oxide same like moisture contents reduces by using silica gel. Hydrogen sulfide concentration was reduced abruptly when it was passed through the chemical absorption tower. It is worth mentioning here that quantity of H_2S abruptly decreased to 18 ppm in treating the biogas even in low concentration of CaO or NaOH and a single treatment even at low concentration is sufficient to remove H_2S from biogas. Results have shown that the chemical absorption method using (CaO+H_2O) has a highly significant effect on the reduction of hydrogen sulfide (H_2S ppm) concentration. The study also suggested that there is no need for a separate H_2S scrubber based on iron wool where the biogas is enriched through chemical absorption technique.

***Conclusions*:** The research was conducted to increase the biogas production rate and to enrich biogas for power generation. Specific algorithms were generated to specify dimensions of the fermentation chamber for a known quantity of biodegradable material. The algorithm was validated by performance evaluation of biogas production. Reverse blasting technique was applied to hinder scum formation in the top half of the digester. As a result of this, an enhanced biogas production rate was obtained. The composition of methane in biogas produced was found to be 45-54% without any alteration to the process. A chemical absorption method was incorporated to obtain methane up to 90% which was further exploited for power generation. The combination of reverse blasting technique and chemical absorption method resulted in not only increasing the biogas production rate but also provided us with enriched biogas. The amalgamation of the described techniques will open new pathways for in-depth analysis of integrated methods for biogas production. With further probing into this research domain will also result in a more economical setup for rural areas.

REFERENCES

Ahmed, S., A. Mahmood, A. Hasan, G.A.S. Sidhu and M.F.U. Butt. 2016. A comparative review of China, India and Pakistan renewable energy sectors and sharing opportunities. Renew. Sust. Energ. Rev. 57:216-225.

Aized, T., M. Shahid, A.A. Bhatti, M. Saleem and G. Anandarajah. 2018. Energy security and renewable energy policy analysis of Pakistan. Renew. Sust. Energ. Rev. 84:155-169.

Al-Addous, M., M. Alnaief, C. Class, A. Nsair, K. Kuchta and M. Alkasrawi. 2017. Technical possibilities of biogas production from olive and date waste in Jordan. BioResour. 12:9383-9395.

Agrahari, R.P. and G.N. Tiwari. 2011. Parametric study of portable floating type biogas plant. Paper read at World Renewable Energy Congress-Sweden; 8-13 May, Linköping; Sweden.

Angelidaki, I. and L. Ellegaard. 2003. Codigestion of manure and organic wastes in centralized biogas plants. Appl. Biochem. Biotechnol. 109:95-105.

Calise, F., C. Cremonesi, G.D.N, di Vastogirardi and M.D. d'Accadia. 2015. Technical and economic analysis of a cogeneration plant fueled by biogas produced from livestock biomass. Energy Procedia. 82:666-673.

di-Perta, E.S., N. Fiorentino, L. Gioia, E. Cervelli, S. Faugno and S. Pindozzi. 2019. Prolonged sampling time increases correlation between wind tunnel and integrated horizontal flux method. Agric. For. Meteorol. 265:48-55.

Donkin, S.S., P.H. Doane and M.J. Cecava. 2013. Expanding the role of crop residues and biofuel co-products as ruminant feedstuffs. Anim. Front. 3:54-60.

Forgacs, A.L., M.N. Kent, M.K. Makley, B. Mets, N. delRaso, G.L. Jahns, L.D. Burgoon Zacharewski and N.V. Reo. 2011. Comparative metabolomic and genomic analyses of TCDD-elicited metabolic disruption in mouse and rat liver. Toxicol. Sci. 125:41-55.

Ghafoor, A., T. Ur-rehman, A. Munir, M. Ahmad and M. Iqbal. 2016. Current status and overview of renewable energy potential in Pakistan for continuous energy sustainability. Renew. Sust. Energ. Rev. 60:1332-1342.

Hosseini, S.E. and M.A. Wahid. 2014. Development of biogas combustion in combined heat and power generation. Renew. Sust. Energ. Rev. 40:868-875.

Jaya, S. and S. Maurya. 2017. Design and development of portable household biogas plant. Int. J. Agric. Eng. 10:208-214.

Knight, R. D. 2008. "Work" In Physics for Scientiests and Engineers: A Strategic Approach, 2nd ed. San Fransisco, U.S.A.: Pearson Addison-Wesley, Pp. 325-327

Naegele, H.J., M. Monch-Tegeder, N.L. Haag and H. Oechsner. 2014. Effect of substrate pretreatment on particle size distribution in a full-scale research biogas plant. Bioresour.Technol. 172:396-402.

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Nsair, A., O.Bade and K. Kuchta. 2018. Development of velocity sensor to optimize the energy yield in a biogas plant. J. Environ. Res. Technol. 1:1-56.

Salminen, E. and J. Rintala. 2002. Anaerobic digestion of organic solid poultry slaughterhouse waste – a review. Bioresour. Technol. 83:13-26.

Samani, M.S., M.A. Abdoli, A. Karbassi, H.R. Pourzamani and M.Rezaee. 2017. Effect of physical and chemical operating parameters on anaerobic digestion of manure and biogas production, A review. J. Environ. Health. Sustain. Develop. 2:235-247.

Sawle, Y., S. Gupta and A.K. Bohre. 2018. Review of hybrid renewable energy systems with comparative analysis of off-grid hybrid system. Renew. Sust. Energ. Rev. 81:2217-2235.

Shah, D., J. Nagarsheth and P. Acharya. 2016. Purification of biogas using chemical scrubbing and application of purified biogas as fuel for automotive engines. Res. J. Recent. Sci. 5:1-7.

Uddin, W., B. Khan, N. Shaukat, M. Majid, G. Mujtaba, A. Mehmood, S. Ali, U. Younas, M. Anwar and A.M. Almeshal. 2016. Biogas potential for electric power generation in Pakistan, A Survey. Renew. Sustain. Energ. Rev. 54:25-33.

Zabaleta, I. and L. Rodic. 2015. Recovery of essential nutrients from municipal solid waste impact of waste management infrastructure and governance aspects. J. Waste Manag. 44:178-187.